CHAPTER 2: ASSESSMENT OF THE PACIFIC COD STOCK IN THE GULF OF ALASKA

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EXECUTIVE SUMMARY

Summary of Major Changes

Relative to the November edition of last year's GOA SAFE report, the following substantive changes have been made in the Pacific cod stock assessment.

Changes in the Input Data

1) Size composition data from the 2002 and January-September 2003 commercial fisheries were incorporated into the model.
2) Catch data for 2003 were incorporated and catch data for 1991-2002 were recompiled.
3) Size composition data from the 2003 GOA bottom trawl survey were incorporated.
4) The biomass estimate from the 2003 GOA bottom trawl survey was incorporated (the 2003 estimate of 297,361 t was up about 6% from the 2001 estimate).
5) Survey biomass estimates for 1984-2001 were recompiled. The biggest change in the time series was the survey estimate for 1987, which decreased by 29%.

Changes in the Assessment Model

No changes were made to the structure of the assessment model.

Changes in Assessment Results

1) The estimated 2004 spawning biomass for the GOA stock is 103,000 t, up about 17% from last year’s estimate for 2003 and up about 26% from last year's F_{ABC} projection for 2004.
2) The estimated 2004 total age 3+ biomass for the GOA stock is 484,000 t, up about 7% from last year’s estimate for 2003 and up about 6% from last year's $F_{40\%}$ projection for 2004.
3) The recommended 2004 ABC for the GOA stock is 62,800 t, up about 19% from last year's recommendation for 2003 and up about 34% from last year’s F_{ABC} projection for 2004.
4) The estimated 2004 OFL for the GOA stock is 102,000 t, up about 46% from last year's estimate for 2003.

Responses to Comments of the Scientific and Statistical Committee (SSC)

SSC Comments Specific to the Pacific Cod Assessments

From the December, 2002 minutes: *"The SSC appreciates the authors attention to SSC comments from the December 2001 minutes with respect to model configuration for selectivity and retrospective analyses, and looks forward to future developments of spawner-recruit relationships for BS/AI cod."* Although this comment was directed to the BSAI Pacific cod assessment, it is equally applicable to the GOA Pacific cod assessment. As in the last two assessments, a provisional stock-recruitment relationship is described in the "Recruitment" subsection of the "Results" section. Additional research, not described in this assessment, has been conducted in support of a new assessment model capable of calculating a statistically valid spawner-recruit relationship for this stock.

SSC Comments on Assessments in General

There were no SSC comments on assessments in general during the last year.

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 63° N latitude. Pacific cod is distributed widely over Gulf of Alaska (GOA), as well as the eastern Bering Sea (EBS) and the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and GOA, and genetic studies (e.g., Grant et al. 1987) have failed to show significant evidence of stock structure within these areas. Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the GOA.

FISHERY

During the two decades prior to passage of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976, the fishery for Pacific cod in the GOA was small, averaging around 3,000 t per year. Most of the catch during this period was taken by the foreign fleet, whose catches of Pacific cod were usually incidental to directed fisheries for other species. By 1976, catches had increased to 6,800 t. Catches of Pacific cod since 1978 are shown in Tables 2.1a and 2.1b. In Table 2.1a, catches for 1978-1990 are broken down by year, fleet sector, and gear type. In Table 2.1b, catches for 1991-2003 are broken down by year, jurisdiction, and gear type. The foreign fishery peaked in 1981 at a catch of nearly 35,000 t. A small joint venture fishery existed through 1988, averaging a catch of about 1,400 t per year. The domestic fishery increased steadily through 1986, then increased more than three-fold in 1987 to a catch of nearly 31,000 t as the foreign fishery was eliminated. Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components. Trawl gear has traditionally accounted for the bulk of the catch (nearly two-thirds on average since 1987). Figure 2.1 shows areas in which sampled hauls for each of the three main gear types (trawl, longline, and pot) were concentrated during 2002. To create this figure, the EEZ off Alaska was divided into 10 km × 10 km squares. A square is shaded if more than two hauls containing Pacific cod were sampled in it during 2002. In the upper panel, the shaded cells represent 89% of the total BSAI/GOA trawl catch; in the middle panel, the shaded cells represent 64% of the total BSAI/GOA longline catch; and in the lower panel, the shaded cells represent 46% of the total BSAI/GOA pot catch.

The history of acceptable biological catch (ABC) and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate commercial catches in Table 2.2. For the first year of management under the MFCMA (1977), the catch limit for GOA Pacific cod was established at slightly less than the 1976 total reported landings. During the period 1978-1981, catch limits varied between 34,800 and 70,000 t, settling at 60,000 t in 1982. Prior to 1981 these limits were assigned for "fishing years" rather than calendar years. In 1981 the catch limit was raised temporarily to 70,000 t and the fishing year was extended until December 31 to allow for a smooth transition to management based on calendar years, after which the catch limit returned to 60,000 t until 1986, when ABC began to be set on an annual basis. From 1986 (the first year in which an ABC was set) through 2003, TAC averaged about 82% of ABC and catch averaged about 88% of TAC. In 8 of these 18 years (44%), TAC equaled ABC exactly. In 6 of these 18 years (33%), catch exceeded TAC. However, it should be noted that all but two of these apparent overages occurred in the most recent five years, when a substantial fishery for Pacific cod was conducted inside State of Alaska waters. To accommodate the State-managed fishery, TAC was set well below ABC in each of those years (15% in 1997 and 1998; 20% in 1999; and 23% in 2000-2003). Thus, the apparent overages in 1999, 2000, 2002, and 2003 are basically an artifact of the bi-jurisdictional nature of the fishery. Catch has exceeded ABC only twice (in 1992 and 1996). Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. For example, from 1986 through 2003, three different assessment models were used (Table 2.2), though the present model has remained unchanged since 1997 (except for the addition of a new fishery selectivity era beginning in 2000).

Historically, the majority of the GOA catch has come from the Central regulatory area. To some extent the distribution of effort within the GOA is driven by regulation, as catch limits within this region have been apportioned by area throughout the history of management under the MFCMA. Changes in area-specific allocation between years have usually been traceable to changes in biomass distributions estimated by Alaska Fisheries Science Center trawl surveys or management responses to local concerns. Currently, the ABC allocation follows the average biomass distribution estimated by the three most recent trawl surveys, and the TAC allocation is within one percent of this distribution on an area-by-area basis. The complete history of allocation (in percentage terms) by regulatory area within the GOA is shown below:

Year(s)	Regulatory Area		
	Western	Central	Eastern
1977-1985	28	56	16
1986	40	44	16
1987	27	56	17
1988-1989	19	73	8
1990	33	66	1
1991	33	62	5
1992	37	61	2
1993-1994	33	62	5
1995-1996	29	66	5
1997-1999	35	63	2
2000-2001	36	57	7
2002 (ABC)	39	55	6
2002 (TAC)	38	56	6
2003 (ABC)	39	55	6
2003 (TAC)	38	56	6

In addition to area allocations, GOA Pacific cod is also allocated on the basis of processor component (inshore/offshore) and season. The inshore component is allocated 90% of the TAC and the remainder is allocated to the offshore component. Within the Central and Western Regulatory Areas, 60% of each component's portion of the TAC is allocated to the A season (January 1 through June 10) and the remainder is allocated to the B season (June 11 through December 31, although the B season directed fishery does not open until September 1). The longline and trawl fisheries are also associated with a Pacific halibut mortality limit which sometimes constrains the magnitude and timing of harvests taken by these two gear types.

An analysis of recent trends in Pacific cod catches by three-digit statistical area, gear, and month is presented in Appendix 2A.

The catches shown in Tables 2.1a-b and 2.2 include estimated discards. Discard rates of Pacific cod in the various GOA target fisheries are shown for each year 1991-2002 in Table 2.3.

DATA

This section describes data used in the current assessment. It does not attempt to summarize all available data pertaining to Pacific cod in the GOA.

Commercial Catch Data

Catch Biomass

Catches (including estimated discards) taken in the GOA since 1978 are shown in Table 2.4, broken down by the three main gear types and the following within-year time intervals, or "periods": January-May, June-August, and September-December. This particular division, which was suggested by participants in the BSAI fishery, is intended to reflect actual intra-annual differences in fleet operation (e.g., fishing operations during the spawning period may be different than at other times of year). In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used.

Catch Size Composition

Fishery size compositions are presently available, by gear, for the years 1978 through the first part of 2003. As in all assessments since 1997, size composition data from trawl catches sampled on shore were not included in the set of input data, because a comparison of cruises for which both at-sea and shoreside size composition samples were available showed that, in the case of trawl catches, the shoreside data typically contained a smaller proportion of small fish than the at-sea data, indicating that these data may reflect post-discard landings rather than the entire catch. For ease of representation and analysis, length frequency data for Pacific cod can usefully be grouped according to the following set of 25 intervals or "bins," with the upper and lower boundaries shown in cm:

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Bound:	9	12	15	18	21	24	27	30	33	36	39	42	45	50	55	60	65	70	75	80	85	90	95	100	105
Upper Bound:	11	14	17	20	23	26	29	32	35	38	41	44	49	54	59	64	69	74	79	84	89	94	99	104	115

Total length sample sizes for each year, gear, and period are shown in Table 2.5. The collections of relative length frequencies are shown by year, period, and size bin for the pre-1987 trawl fishery in Table 2.6, the pre-1987 longline fishery in Table 2.7, the post-1986 trawl fishery in Tables 2.8a and 2.8b, the post-1986 longline fishery in Tables 2.9a and 2.9b, and the pot fishery in Tables 2.10a and 2.10b.

Survey Data

Survey Size Composition and Abundance Estimates

The relative size compositions from trawl surveys of the GOA conducted triennially by the Alaska Fisheries Science Center since 1984 are shown in Table 2.11, using the same length bins defined above for the commercial catch size compositions. Total sample sizes are shown below:

Year:	1984	1987	1990	1993	1996	1999	2001	2003
Sample size:	17413	19589	11440	17152	12190	8645	6772	9125

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl surveys are shown in Table 2.12, together with the standard errors and upper and lower 95% confidence intervals (CI) for the biomass estimates. The survey time series was recompiled for this year's assessment. Most of the estimates changed relatively little, except for the 1987 survey estimate, which decreased by 29%.

The highest biomass ever observed by the survey was the 1984 estimate of 550,971 t, and the low point is the 2001 estimate of 279,332 t (the 2001 estimate was obtained by summing the 2001 estimate for the Western and Central areas with the 1999 estimate for the Eastern area, because the 2001 survey did not cover the Eastern area) . In terms of population numbers, the record high was observed in 1984, when the population was estimated to include over 321 million fish.

Length at Age, Weight at Length, and Maturity at Length

The set of reliable length at age data for GOA Pacific cod has been small for the past several years and such data are used only sparingly in this assessment. The otoliths which have been read provide the following data regarding the relationship between age and length and the amount of spread around that relationship (lengths are in cm and ages are back-dated to January 1):

Age group:	3	4	5	6	7	8	9	10	11	12
Average length:	45	52	60	66	74	81	85	90	94	95
St. dev. of length:	2.6	3.5	3.8	4.0	3.9	5.0	6.2	6.9	5.5	7.0

Although the supply of reliable length at age data has been severely limited in the past, it now appears likely that such data will become much more available in the future. Studies at the Alaska Fisheries Science Center have resulted in an ageing methodology for Pacific cod that gives reliable age determinations, and production ageing of this species has recently begun (Delsa Anderl, pers. commun.).

Weight measurements taken during summer bottom trawl surveys since 1987 yield the following data regarding average weights (in kg) at length, grouped according to size composition bin (as defined under "Catch Size Composition" above):

Bin Number:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ave. weight:	n/a	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	1.1	1.5	2.0	2.5	3.2	4.0	5.2	6.3	8.0	9.5	11.5	13.2	13.9

The best available data on maturity consist of observers' visual determinations regarding the spawning condition of 2312 females taken in the EBS fishery in 1994. These are used as proxy data for the GOA stock. Of these 2312 females, 231 were smaller than 42 cm (the lower boundary of length bin 12). None of these sub-42 cm fish were mature. The observed proportions of mature fish in the remaining length bins, together with the numbers of fish sampled in those length bins, are shown below (bins are defined under "Catch Size Composition" above):

Bin number:	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Prop. mature:	0.03	0.05	0.14	0.19	0.28	0.53	0.69	0.82	0.89	0.94	0.94	0.91	0.89	1.00
Sample size:	39	122	226	313	295	300	320	177	103	70	50	35	19	12

ANALYTIC APPROACH

Model Structure

This year's base model structure is identical to the base model structure used in all assessments of the GOA Pacific cod stock since 1997 (Thompson et al. 1997). Beginning with the 1994 SAFE report (Thompson and Zenger 1994), a length-structured Synthesis model (Methot 1986, 1989, 1990, 1998) has formed the primary analytical tool used to assess the GOA Pacific cod stock. Synthesis is a program that uses the parameters of a set of equations governing the assumed dynamics of the stock (the “model parameters”) as surrogates for the parameters of statistical distributions from which the data are assumed to be drawn (the “distribution parameters”), and varies the model parameters systematically in the direction of increasing likelihood until a maximum is reached. The overall likelihood is the product of the likelihoods for each of the model components. Each likelihood component is associated with a set of data assumed to be drawn from statistical distributions of the same general form (e.g., multinomial, lognormal, etc.). Typically, likelihood components are associated with data sets such as catch size (or age) composition, survey size (or age) composition, and survey biomass.

The Synthesis program permits each data time series to be divided into multiple segments, or “eras,” resulting in a separate set of parameter estimates for each era. To account for possible differences in selectivity between the mostly foreign (also joint venture) and mostly domestic fisheries, the fishery size composition time series in the base model has traditionally been split into pre-1987 and post-1986 eras. A minor modification of the base model was suggested by the SSC in 2001, namely, that consideration be given to dividing the domestic era into pre-2000 and post-1999 segments. This modification was tested in the 2002 assessment (Thompson et al. 2002) and was found to result in a statistically significant improvement in the model’s ability to fit the data. Therefore, the present assessment treats the post-1999 fisheries separately from the 1978-1986 and 1987-1999 fisheries.

Symbols used in the stock assessment model are listed in Table 2.13 (note that this list applies to the stock assessment model only, and does not include all symbols used elsewhere in this document). Synthesis uses a total of 16 dimensional constants, special values of indices, and special values of continuous variables, all of which are listed on the first page of Table 2.13. The values of these quantities are not estimated statistically, in the strict sense, but are typically set by assumption or as a matter of structural specification. The values of these constants, indices, and variables are listed in Table 2.14, with a brief rationale given for each value used. In contrast to the quantities whose values are specified in Table 2.14, Synthesis uses a large number of parameters that are estimated statistically (though the estimation itself may not necessarily take place within Synthesis). For ease of reference, capital Roman letters are used to designate such “Synthesis parameters,” which are listed on the second page of Table 2.13. Functional representations of population dynamics are given in Appendix 2A of the 2002 stock assessment (Thompson et al. 2002).

The assessments conducted during the period 1997-1999 (Thompson et al. 1997, Thompson et al. 1998, Thompson et al. 1999) used approximate Bayesian methods to address uncertainty surrounding the true values of two key model parameters, the natural mortality rate M and the survey catchability coefficient Q. Due to limitations of the Synthesis software, a type of meta-analysis was used to implement the Bayesian portion of those assessments. This meta-analysis involved fitting a pair of bivariate distributions to the log-likelihood maxima and projected $F_{40\%}$ catches returned from a very large number of individual model runs, each of which held M and Q constant at a unique pair of values. The pairs of M and Q values corresponded to points placed at regularly spaced intervals within a grid spanning the 95% confidence ellipse of the fitted bivariate log-likelihood surface. The purpose of the Bayesian meta-analysis was to recommend an ABC that accounted for parameter uncertainty in an appropriately risk-averse manner. This was accomplished by setting the recommended ABC equal to the geometric mean of the catch distribution corresponding to the product of the catch profile and the posterior distribution. However, the Bayesian meta-analysis was always extremely labor intensive. In the course of conducting the 2000 stock assessment (Thompson et al. 2000), it therefore seemed prudent to seek an efficient shortcut. Looking back at the results of the 1997-1999 stock assessments, it appeared that the ratio between the recommended F_{ABC} emerging from the Bayesian meta-analysis and the $F_{40\%}$ estimate emerging from the base model was converging over time. The average value of this ratio over the 1997-1999 period was 0.86, with a 1999 value of 0.87. Interestingly, identical three-year average and 1999 values were obtained in the 1997-1999 assessments of the BSAI Pacific cod stock (Thompson and Dorn 1997, Thompson and Dorn 1998, Thompson and Dorn 1999). Because the 1999 value represented the most recent estimate and was approximately equal to the 1997-1999 average, the 2000-2002 stock assessments multiplied this value (0.87) by the maximum permissible F_{ABC} to obtain the recommended F_{ABC}. The same procedure is retained in the present assessment as well, thereby eliminating the need to re-perform the Bayesian meta-analysis.

Parameters Estimated Independently

Table 2.15 divides the set of Synthesis parameters into two parts, the first of which lists those parameters that were estimated independently (i.e., outside of Synthesis), and the second of which lists those parameters that were estimated conditionally (i.e., inside of Synthesis). This section describes the estimation of parameters in the first part of Table 2.15.

Natural Mortality

The natural mortality rate was estimated independently of other parameters at a value of 0.37. This value was used in the present assessment for the following reasons: 1) it was derived as the maximum likelihood estimate of *M* in the 1993 BSAI Pacific cod assessment (Thompson and Methot 1993), 2) it has been used to represent *M* in all BSAI Pacific cod assessments since 1993 and in all GOA Pacific cod assessments except one since 1994, 3) it was explicitly accepted by the SSC for use as an estimate of *M* in the GOA Pacific cod assessment (SSC minutes, December, 1994), and 4) it lies well within the range of previously published estimates of *M* shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

Trawl Survey Catchability

The trawl survey catchability coefficient was estimated independently of other parameters at a value of 1.0. This value was used in the present assessment mostly because it had been used in all previous assessments. Also, preliminary results of recent experimental work conducted in the EBS by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division tend to confirm that this is a reasonable value (David Somerton, pers. commun.).

Weight at Length

Parameters (Table 2.13) governing the relationship between weight and length (Appendix 2A) were estimated by regression from the available data (see "Data" above), giving the following values (weights are in kg, lengths in cm): $W_1 = 5.80 \times 10^{-6}$, $W_2 = 3.159$.

Length at First Age of Survey Observation

Assuming that the first age at which Pacific cod are seen in the trawl survey (α_1, Table 2.13) is approximately 1.5 years, the length at this age (L_1, Table 2.13) was estimated to be 19.8 cm by averaging the lengths corresponding to the first mode greater than or equal to 14 cm (bin 2) from each of the five most recent survey size compositions.

Variability in Length at Age

Parameters (Table 2.13) governing the amount of variability surrounding the length-at-age relationship (Appendix 2A) were estimated by linear regression from the observed standard deviations in the available length-at-age data (see "Data" above), giving the following values (in cm): $X_1 = 1.8$, $X_2 = 6.9$. Estimation of these two parameters constituted the only use of age data in the present assessment.

Maturity at Length

Maximum likelihood estimates of the parameters (Table 2.13) governing the female maturity-at-length schedule (Appendix 2A) were obtained using the method described by Prentice (1976), giving the following values: $P_1 = 0.142$, $P_2 = 67.1$ cm. The variance-covariance matrix of the parameter estimates gave a standard deviation of 0.006 for the estimate of P_1, a standard deviation of 0.39 cm for the estimate of P_2, and a correlation of -0.154 between the estimates of the two parameters.

Parameters Estimated Conditionally

Those Synthesis parameters that are estimated internally are listed in the second part of Table 2.15. The estimates of these parameters are conditional on each other, as well as on those listed in the first part of the table and discussed in the preceding section (i.e., those Synthesis parameters that are estimated independently).

Likelihood Components

As noted in the "Model Structure" section, Synthesis is a likelihood-based framework for parameter estimation which allows several data components to be considered simultaneously. In this assessment, four fishery size composition likelihood components were included: the January-May ("early") trawl fishery, the June-December ("late") trawl fishery, the longline fishery, and the pot fishery. In addition to the fishery size composition components, likelihood components for the size composition and biomass trend from the bottom trawl survey were included in the model.

The Synthesis program allows the modeler to specify "emphasis" factors that determine which components receive the greatest attention during the parameter estimation process. As in previous assessments, all components were given an emphasis of 1.0 in the present assessment.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear/fishery, and time period within the year. In the parameter estimation process, Synthesis weights a given size composition observation (i.e., the size frequency distribution observed in a given year, gear/fishery, and period) according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which Synthesis was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. As in previous assessments, the present assessment uses a multinomial sample size equal to the square root of the true sample size, rather than the true sample size itself. Given the true sample sizes observed in the present assessment, this procedure tends to give values somewhat below 400 while still providing the Synthesis program with usable information regarding the appropriate effort to devote to fitting individual samples. Multinomial sample sizes derived by this procedure for the commercial fishery size compositions are shown in Table 2.16. In the case of survey size composition data, the square root (SR) assumption was also used, giving the multinomial sample sizes shown below:

Year:	1984	1987	1990	1993	1996	1999	2001	2003
SR(sample size):	132	140	107	131	110	93	82	96

Use of Survey Biomass Data in Parameter Estimation

Each year's survey biomass datum is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey biomass in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey biomass datum's standard error to the survey biomass datum itself serves as the distribution's coefficient of variation.

MODEL EVALUATION

Evaluation Criteria

Three criteria were used to evaluate the stock assessment model: 1) the effective sample sizes of the size composition data, 2) the root mean squared error (RMSE) of the fit to the survey biomass data, and 3) the overall reasonableness of the results.

Effective Sample Size

Once maximum likelihood estimates of the model parameters have been obtained, Synthesis computes an “effective” sample size for the size composition data specific to a particular year, gear/fishery, and time period within the year. Roughly, the effective sample size can be interpreted as the multinomial sample size that would typically be required in order to produce the given fit. More precisely, it is the sample size that sets the sum of the marginal variances of the proportions implied by the multinomial distribution equal to the sum of the squared differences between the sample proportions and the estimated proportions (McAllister and Ianelli 1997). As a function of a multinomial random variable, the effective sample size has its own distribution. The harmonic mean of the distribution is equal to the true sample size in the multinomial distribution. Thus, if the effective sample size is less than the true sample size in the multinomial distribution, it is reasonable to conclude that the fit is not as good as expected. The following table shows the average of the input sample sizes and the average effective sample sizes for each of the size composition components (in each column, the average is computed with respect to all years and periods present in the respective time series):

Size composition likelihood component	Average effective sample size	Average input sample size	Ratio (effective divided by input)
Early-season trawl fishery	303	129	2.34
Late-season trawl fishery	89	39	2.27
Longline fishery	313	88	3.54
Pot fishery	344	92	3.75
Bottom trawl survey	163	111	1.46
All	263	85	3.08

The model produces average effective sample sizes considerably larger than the average input values for all components.

Observed and estimated size compositions in the January-May fisheries in 2000, 2001, and 2002 are compared in Figures 2.2, 2.3, and 2.4. Observed and estimated size compositions from the three most recent bottom trawl surveys are compared in Figure 2.5.

Fit to Survey Biomass Data

The root-mean-squared value of the lognormal “sigma” parameter in the survey biomass data is 0.165. The log-scale RMSE from the model is 0.153, very close to the root-mean-squared-sigma.

Overall Reasonableness of Results

The model’s estimates of length-at-age parameters K and L_2 (L_1 was estimated independently, and thus did not vary with choice of model) are shown below:

Parameter	Estimate
K	0.150
L_2	85.2

Model estimates of fishing mortality rates $F_{g,y,i}$, recruitments R_y and initial numbers at age N_a, and selectivity parameters $S_{1\text{-}7,g,e(y|g)}$ are shown in Tables 2.17, 2.18, and 2.19, respectively.

Model estimates of age 3+ biomass, spawning biomass, and survey biomass are shown in Table 2.20 and Figure 2.6.

All of the above appear reasonable, with the possible exception of the relationship between age 3+ biomass and survey biomass (Table 2.20, Figure 2.6). On average, the model's estimate of age 3+ biomass exceeds the observed survey biomass by about 68%. While this result is biologically possible, there is no obvious reason why it should be expected.

Schedules Defined by Final Parameter Estimates

Lengths at age defined by the final parameter estimates are shown below (lengths are in cm and are evaluated at the mid-point of each age group):

Age group:	1	2	3	4	5	6	7	8	9	10	11	12
Average length:	20	32	42	50	57	64	69	74	78	81	84	89

The distribution of lengths at age (measured in mid-year) defined by the final parameter estimates is shown in Table 2.21.

Weights at length and maturity proportions at length defined by the final parameters are shown in Table 2.22, and selectivities at length defined by the final parameter estimates are shown in Table 2.23.

RESULTS

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 3+ biomass, consisting of the biomass of all fish aged three years or greater in January of a given year; 2) spawning biomass, consisting of the biomass of all spawning females in March of a given year; and 3) survey biomass, consisting of the biomass of all fish that the Model estimates should have been observed by the survey in July of a given year. The recruitment estimates presented here will be defined in two ways: 1) as numbers of age 3 fish in January of a given year and 2) as the recruitment parameter R_y, which represents numbers at age 1 in January of year y. The fishing mortality rates presented here will be defined as full-selection, instantaneous fishing mortality rates expressed on a per annum scale.

Biomass

The model's description of the recent history of the stock is shown in Table 2.24, together with estimates provided in last year's final SAFE report (Thompson et al. 2002). The biomass trends estimated in the present assessment are also shown in Figure 2.6. The age 3+ biomass trend shows an increase throughout the 1980s followed by a period of sustained high abundance during the early 1990s, followed by a steady decline through the present. Roughly paralleling the estimated age 3+ biomass trend, the model's estimated spawning and survey biomass trends show declines throughout the past decade. The model's estimates of 2003 age 3+ and spawning biomass are the lowest in their respective time series since the 1970s.

Figure 2.7 compares this year's estimate of the survey biomass time series with those from all other assessments since 1997 (the year in which the base model was standardized). Prior to the present assessment, these annual estimates have been remarkably consistent: If each assessment's estimate of the survey biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have ranged from a low of 0.939 (using the 2001 estimates to predict the 2002 estimates) to a high of 0.997 (using the 1998 estimates to predict the 1999 estimates), and no time trend is obvious. However, the survey biomass time series estimated by the present assessment is noticeably different from those estimated by previous assessments. For example, if the 2002 estimates had been used to predict the 2003 assessments, the R^2 would have been only 0.406. This is most likely due to the revised survey biomass time series used in the present assessment, particularly the revised survey biomass for 1987, which is 29% lower than the value used previously.

Figure 2.8 compares this year's estimate of the age 3+ biomass time series with those from all other assessments since 1997. These annual estimates show less interannual consistency than the model's estimates of survey biomass. If each assessment's estimate of the age 3+ biomass time series had been used to predict the next assessment's estimate of the same time series, the R^2 would have exceeded 90% in half of the cases, but could also range as low as -0.102 (using the 2000 estimates to predict the 2001 estimates). Using the 2002 estimates to predict the 2003 estimates results in an R^2 of 0.643. As Figure 2.8 shows, the 2003 assessment resulted in an estimated age 3+ biomass time series that was lower than any other for the early portion of the time series. Conversely, the 2003 assessment's estimates of age 3+ biomass for the most recent six years were consistently higher than those from the 2002 assessment. To attempt to measure whether there is a consistent trend (i.e., retrospective bias) between assessments, the relative change in each year's age 3+ biomass estimate as assessed between each pair of successive assessments was computed (e.g., the relative change in the estimated value of age 3+ biomass for 1985 as assessed in, say, the 2000 and 2001 assessments), then the relative changes were averaged for each pair of successive assessments, resulting in the values shown below:

First assessment year	1997	1998	1999	2000	2001	2002
Second assessment year	1998	1999	2000	2001	2002	2003
Average relative change in age 3+ biomass	0.022	-0.013	0.012	-0.142	0.038	-0.044

Given that the sign of the average relative change alternates every year, it is reasonable to conclude that these assessments do not show a consistent retrospective bias.

Figure 2.9 plots the trajectory of fishing mortality and female spawning biomass from 1978 through 2003, overlaid with the current harvest control rules. The entire trajectory lies underneath both harvest control rules. In other words, fishing mortality rates have been well within the current limits throughout the period in which those limits have been in effect, although it should be noted that the current harvest control rules did not go into effect until 1999.

Recruitment

Numbers at Age 3

Traditionally, recruitment strengths for Pacific cod have been assessed at age 3, because this is the approximate age of first significant recruitment to the fishery and because model estimates of relative year class strength tend to stabilize by this age. The model's estimated time series of age 3 recruitments is shown in Table 2.25, together with the estimates provided in last year's final SAFE report (Thompson et al. 2002). The model's recruitment estimates are also plotted in Figure 2.10. The current time series has a mean value of 134 million fish, a coefficient of variation of 30%, and an autocorrelation coefficient of 0.08.

One possible means of assigning a qualitative ranking to each year class within this time series is as follows: an "above average" year class can be defined as one in which numbers at age 3 are at least 120% of the mean, an "average" year class can be defined as one in which numbers at age 3 are less than 120% of the mean but at least 80% of the mean, and a "below average" year class can be defined as one in which numbers at age 3 are less than 80% of the mean. These criteria give the following classification of year class strengths:

Above average:	1976	1977	1979	1984	1987	1989								
Average:	1980	1981	1983	1985	1986	1988	1990	1991	1992	1993	1994	1995	1999	2000
Below average:	1975	1978	1982	1996	1997	1998								

With respect to last year's assessment (Thompson et al. 2002), the changes in the above table consist of a downgrade in the strength of the 1980 year class from "above average" to "average," an upgrade in the strength of the 1976 year class from "average" to "above average," downgrades in the strength of the 1978 and 1982 year classes from "average" to "below average," upgrades in the strength of the 1992 and 1999 year classes from "below average" to "average," and the addition of the 2000 year class to the "average" category.

Numbers at Age 1

The model's estimated time series of age 1 recruitments is shown in Table 2.18. This time series has a mean value of 270 million fish, a coefficient of variation of 35%, and an autocorrelation coefficient of 0.35. (It should be noted that the strength of the autocorrelation is heavily dependent on the estimates of the last two year classes, which are probably the most imprecisely estimated year classes in the time series. With those two year classes removed, the autocorrelation coefficient drops to 0.10.) The qualitative rankings of year class strengths at age 1 naturally parallel the rankings at age 3, except that estimates for the 1975 and 1976 year classes do not exist at age 1 and the 2001 and 2002 year classes are added to the time series. The 2001 and 2002 year classes are presently estimated to be much weaker than any other year class in the time series, but it should be emphasized that the estimates of these two year classes are based on relatively few data (survey length compositions at ages 1 or 1 and 2).

The present assessment model is not configured to estimate a stock-recruitment relationship. Estimation of stock-recruitment relationships is a notoriously difficult exercise in the field of stock assessment, because both the stock data and the recruitment data are measured with error and because the errors in the stock-recruitment data are autocorrelated (Walters and Ludwig 1981). Also, if the stock and recruitment data are generated by a model which assumes that no stock-recruitment relationship exists, these data will be biased. Nevertheless, the stock-recruitment relationship is potentially such an important component of stock dynamics that it seems prudent to provide some kind of investigation, albeit provisional, as to its possible shape. In addition, the SSC has requested that the assessment include a stock-recruitment relationship (SSC minutes, December, 2000; December, 2001; and December, 2002). To this end, the following analysis was conducted (use of symbols in this description does not necessarily follow Table 2.13, which pertains to the Synthesis assessment model only):

1) Age 1 recruitment *R* in year *y*+1 was assumed to be related to spawning biomass *S* in year *y* by the Ricker (1954) stock-recruitment relationship subject to lognormal error:

$$R_{y+1} = S_y \exp\left(-\alpha - \beta S_y + \varepsilon_y\right),$$

where α and β are parameters and the ε_y are drawn from a normal distribution with mean 0 and variance σ^2.
2) The estimates of spawning biomass generated by Synthesis were treated as known constants (i.e., it was assumed that they are measured without error).
3) Parameters were estimated by the method of maximum likelihood.
4) The covariance of the parameter estimates was assumed to equal the inverse of the Hessian matrix.

The point estimates of the parameters were α = -0.524, β = -0.000142, and σ = 0.376. The 95% confidence interval of the stock-recruitment parameters is shown in the upper panel of Figure 2.11. One of the attractive features of the method described above is that it implies that the stock-recruitment relationship $r(S) = S\exp(-\alpha-\beta S)$ is itself a lognormal random variable with parameters that are functions of stock size. The coefficient of variation for the relationship is minimized at the mean of the stock data. The lower panel of Figure 2.11 shows the data (solid squares), the stock-recruitment relationship defined by the point estimates of the parameters (thick curve), and the 95% confidence interval around the stock-recruitment relationship (thin curves). This analysis is useful mostly because it indicates a considerable level of uncertainty regarding the shape of the stock-recruitment relationship. Moreover, this description of uncertainty should be regarded as an underestimate because of the problems noted in the paragraph above. The estimates given here are not recommended for use in estimating maximum sustainable yield.

Exploitation

The model's estimated time series of the ratio between catch and age 3+ biomass is shown in Table 2.26, together with the estimates provided in last year's final SAFE report (Thompson et al. 2002). The average value of this ratio over the entire time series is about 0.073. The estimated values meet or exceed the average for every year after 1989 except 1993 and 1994, whereas the estimated values fall below the average for every year prior to 1990.

PROJECTIONS AND HARVEST ALTERNATIVES

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) *Stock status:* $B/B_{40\%} > 1$
$F_{OFL} = F_{35\%}$
$F_{ABC} \leq F_{40\%}$
3b) *Stock status:* $1/20 < B/B_{40\%} \leq 1$
$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 1/20) \times 20/19$
$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 1/20) \times 20/19$
3c) *Stock status:* $B/B_{40\%} \leq 1/20$
$F_{OFL} = 0$
$F_{ABC} = 0$

Estimation of the $B_{40\%}$ reference point used in the above formulae requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the post-1976 average (i.e., the arithmetic mean of all estimated recruitments from year classes spawned in 1977 or later). Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. These reference points are estimated as follows:

Reference point:	$B_{35\%}$	$B_{40\%}$	$B_{100\%}$
Spawning biomass:	77,800 t	88,900 t	222,000 t

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. In this assessment, total fishing mortality was apportioned between gear types (early trawl, late trawl, longline, and pot) at a ratio of 290:53:173:484. These proportions result in a 2003 catch composition that matches the recent (1999-2001) average distribution of catches between the trawl and fixed-gear fisheries, between the early and late trawl fisheries, and between the longline and pot fisheries. It should be noted that this apportionment scheme is generally consistent with existing Steller sea lion protection measures. This apportionment results in the following estimates of $F_{35\%}$ and $F_{40\%}$:

$F_{35\%}$	$F_{40\%}$
0.41	0.34

Specification of OFL and Maximum Permissible ABC

Spawning biomass for 2004 is estimated at a value of 103,000 t. This is about 16% above the $B_{40\%}$ value of 88,900 t, thereby placing Pacific cod in sub-tier "a" of Tier 3. Given this, the model estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2004 as follows:

	Overfishing Level	Maximum Permissible ABC
Catch:	83,700 t	71,200 t
Fishing mortality rate:	0.41	0.34

The age 3+ biomass estimate for 2004 is 484,000 t.

ABC Recommendation

It is important to remember that the maximum permissible ABC computed under the stock assessment model is only a point estimate, around which there is significant uncertainty. For the past several years, the BSAI and GOA Pacific cod assessments have advocated a harvest strategy that formally addresses some of this uncertainty, namely the uncertainty surrounding parameters M and Q (see "Model Structure" above). For the 2000-2002 assessments, the strategy was simplified by assuming that the ratio between the recommended F_{ABC} and $F_{40\%}$ estimate given in the 1999 assessment (0.87) was an appropriate factor by which to multiply the current maximum permissible F_{ABC} to obtain a recommended F_{ABC}. The same strategy is recommended for setting the 2004 ABC. This strategy results in a recommended 2004 ABC of 62,800 t, corresponding to a fishing mortality rate of 0.29.

Area Allocation of Harvests

The time series of area-specific survey biomass estimates (t) is shown below, in reverse order of year (the 2001 estimate for the Eastern area is set equal to the 1999 estimate because the 2001 survey did not cover the Eastern area):

Year	Western	Central	Eastern
2003	75,052	207,619	14,689
2001	133,214	124,400	21,718
1999	112,076	172,620	21,718
1996	188,128	337,388	12,638
1993	120,122	269,258	20,468
1990	129,744	262,732	25,725
1987	72,312	289,790	32,886
1984	173,843	340,336	36,792

Running averages of the weighted proportions of area-specific survey biomass estimates is shown below (e.g., the proportions in the second row below equal the relative weighted averages of the biomass estimates in the first two rows of the table above, the proportions in the third row below equal the relative weighted averages of the biomass estimates in the first three rows of the table above, etc.):

Year	Western	Central	Eastern
2003	0.25	0.70	0.05
2001	0.36	0.58	0.06
1999	0.36	0.57	0.07
1996	0.36	0.59	0.05
1993	0.34	0.61	0.05
1990	0.34	0.61	0.05
1987	0.31	0.63	0.06
1984	0.31	0.63	0.06

Recently, ABC has been allocated on the basis of the three most recent surveys. If this approach is continued for the 2004 fishery, the proportions would be 36% Western, 57% Central, and 7% Eastern.

Standard Harvest and Recruitment Scenarios and Projection Methodology

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2004 recommended in the assessment to the *max* F_{ABC} for 2004. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of *max* F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1998-2002 average F, which was 0.30. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2004 or 2) above ½ of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

Scenario 7: In 2004 and 2005, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2016 under this scenario, then the stock is not approaching an overfished condition.)

Projections and Status Determination

Table 2.27 defines symbols used to describe projections of spawning biomass, fishing mortality rate, and catch corresponding to the seven standard harvest scenarios. These projections are shown in Tables 2.28-34.

Harvest scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest scenarios #6 and #7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2004:

a) If spawning biomass for 2004 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b) If spawning biomass for 2004 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c) If spawning biomass for 2004 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario #6 (Table 2.33). If the mean spawning biomass for 2014 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest scenario #7 (Table 2.34):

a) If the mean spawning biomass for 2006 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b) If the mean spawning biomass for 2006 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c) If the mean spawning biomass for 2006 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2016. If the mean spawning biomass for 2016 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

In the case of GOA Pacific cod, spawning biomass for 2004 is estimated to be above $B_{35\%}$. Therefore, the stock is above its MSST and is not overfished. Mean spawning biomass for 2006 in Table 2.34 is above $B_{35\%}$. Therefore, the stock is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the BSAI Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Livingston, ed., 2002). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000).

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), and Westrheim (1996). In terms of percent occurrence, the most important items in the diet of Pacific cod in the BSAI and GOA are polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, the most important dietary items are euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, the most important dietary items are walleye pollock, fishery offal, and yellowfin sole. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Bycatch of Nontarget and "Other" Species

The methods described by Gaichas (2002) were used to estimate the bycatch imposed by the GOA Pacific cod fisheries on various nontarget species and members of the "other species" group. Tables 2.35a-c show these estimates in terms of both absolute bycatch amounts (metric tons or number of individuals, depending on the species group) and proportions of the total bycatch for each species group. Table 2.35a shows estimates for the trawl fishery, Table 2.35b shows estimates for the longline fishery, and Table 2.35c shows estimates for the pot fishery.

It is not clear how much bycatch of a particular species constitutes "too much" in the context of ecosystem concerns. As a first step toward possible prioritization of future investigation into this question, it might be reasonable to focus on those species groups for which a Pacific cod fishery had a bycatch in excess of 100 t and accounted for more than 10% of the total bycatch in at least half of the six most recent years. This criterion results in the following list of impacted species groups (an "x" indicates that the criterion was met for that area/species/gear combination).

Area	Species group	Trawl	Longline	Pot
GOA	sculpins	x	x	x
GOA	skates	x	x	
GOA	dogfish		x	
GOA	octopus			x
GOA	starfish		x	x

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery operates to some extent in the same geographic areas used by Steller sea lion as foraging grounds (Livingston, ed., 2002).

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the longline fishery for Pacific cod. Shearwater

(*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (BS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed sets was as follows:

Gear	BS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the BS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort was dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

Data Gaps and Research Priorities

Understanding of the above ecosystem considerations would be improved if future research were directed toward closing certain data gaps. Such research would have several foci, including the following: 1) ecology of the Pacific cod stock, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) behavior of the Pacific cod fishery, including spatial dynamics; 3) determinants of trawl survey selectivity; 4) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 5) ecology of species that interact with Pacific cod, including estimation of biomass, carrying capacity, and resilience.

SUMMARY

The major results of the Pacific cod stock assessment are summarized in Table 2.36.

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Table 2.1a--Summary of catches (t) of Pacific cod prior to 1991 by fleet sector and gear type. All catches since 1980 include discards. Jt. Vent. = joint venture.

Year	Fleet Sector			Gear Type				Total
	Foreign	Jt. Vent.	Domestic	Trawl	Longline	Pot	Other	
1978	11,370	7	813	4,547	6,800	0	843	12,190
1979	13,173	711	1,020	3,629	9,545	0	1,730	14,904
1980	34,245	466	634	6,464	27,780	0	1,101	35,345
1981	34,969	58	1,104	10,484	25,472	0	175	36,131
1982	26,937	193	2,335	6,679	22,667	0	119	29,465
1983	29,777	2,426	4,337	9,512	26,756	0	272	36,540
1984	15,896	4,649	3,353	8,805	14,844	0	249	23,898
1985	9,086	2,266	3,076	4,876	9,411	2	139	14,428
1986	15,211	1,357	8,444	6,850	17,619	141	402	25,012
1987	0	1,978	30,961	22,486	8,261	642	1,550	32,939
1988	0	1,661	32,141	27,145	3,933	1,422	1,302	33,802
1989	0	0	43,293	37,637	3,662	376	1,618	43,293
1990	0	0	72,517	59,188	5,919	5,661	1,749	72,517

Table 2.1b--Summary of catches (t) of Pacific cod since 1991 by management jurisdiction and gear type. Longl. = longline, Subt. = subtotal. All entries include discards. Catches for 2003 are complete through October.

	Federal					State			
Year	Trawl	Longl.	Pot	Other	Subt.	Pot	Other	Subt.	Total
1991	58,093	7,656	10,464	115	76,328	0	0	0	76,328
1992	54,593	15,675	10,154	325	80,746	0	0	0	80,746
1993	37,806	8,962	9,708	11	56,487	0	0	0	56,487
1994	31,446	6,778	9,160	100	47,484	0	0	0	47,484
1995	41,875	10,978	16,055	77	68,985	0	0	0	68,985
1996	45,991	10,196	12,040	53	68,280	0	0	0	68,280
1997	48,405	10,977	9,065	26	68,474	7,224	1,319	8,542	77,017
1998	41,569	10,011	10,510	29	62,120	9,088	1,316	10,404	72,524
1999	37,167	12,362	19,015	70	68,613	12,075	1,096	13,171	81,784
2000	25,457	11,667	17,351	54	54,528	10,388	1,643	12,031	66,559
2001	24,382	9,913	7,171	155	41,621	7,836	2,084	9,920	51,541
2002	19,809	14,666	7,694	176	42,345	10,423	1,714	12,137	54,483
2003	18,527	9,335	12,611	236	40,710	8,081	3,483	11,564	52,274

Table 2.2--History of Pacific cod ABC, TAC, total catch, and type of stock assessment model used to recommend ABC. ABC was not used in management of GOA groundfish prior to 1986. Catch for 2003 is current through October. The values in the column labeled "TAC" correspond to "optimum yield" for the years 1980-1986, "target quota" for the year 1987, and true TAC for the years 1988-2003.

Year	ABC	TAC	Catch	Stock Assessment Model
1980	n/a	60000	35345	n/a
1981	n/a	70000	36131	n/a
1982	n/a	60000	29465	n/a
1983	n/a	60000	36540	n/a
1984	n/a	60000	23898	n/a
1985	n/a	60000	14428	n/a
1986	136000	75000	25012	survey biomass
1987	125000	50000	32939	survey biomass
1988	99000	80000	33802	survey biomass
1989	71200	71200	43293	stock reduction analysis
1990	90000	90000	72517	stock reduction analysis
1991	77900	77900	76328	stock reduction analysis
1992	63500	63500	80746	stock reduction analysis
1993	56700	56700	56487	stock reduction analysis
1994	50400	50400	47484	stock reduction analysis
1995	69200	69200	68985	length-structured Synthesis model
1996	65000	65000	68280	length-structured Synthesis model
1997	81500	69115	68474	length-structured Synthesis model
1998	77900	66060	62102	length-structured Synthesis model
1999	84400	67835	68613	length-structured Synthesis model
2000	76400	58715	65905	length-structured Synthesis model
2001	67800	52110	42022	length-structured Synthesis model
2002	57600	44230	44734	length-structured Synthesis model
2003	52800	40540	52274	length-structured Synthesis model

Table 2.3–Pacific cod discard rates by area, target species/group, and year. The discard rate is the ratio of discarded Pacific cod catch to total Pacific cod catch for a given area/target/year combination. An empty cell indicates that no Pacific cod were caught in that area/target/year combination. Note that the absolute amount of discards may be small even if the discard rate is large.

Target species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Arrowtooth flounder		0.98	0.59	0.00	0.10	0.09	0.00	1.00	0.63	0.06		0.00
Atka mackerel				0.81	1.00	0.00						
Deepwater Flat	1.00			0.43	0.00	0.68	0.53	0.00	0.36	0.00	0.75	
Flathead sole				1.00		0.07	0.99	0.00		0.29	0.75	0.00
Other species	1.00	0.15	0.63		0.10	0.91	0.00	0.00	0.96	0.01	0.00	0.00
Pacific cod	0.05	0.03	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.00	0.02	0.02
Pollock	0.82	0.59	0.15	0.15	0.95	0.17	0.98	0.75	0.89	0.44	0.00	1.00
Rex sole					0.16	0.25	0.61	0.57				1.00
Rockfish	0.15	0.11	0.13	0.16	0.11	0.13	0.14	0.17	0.17	0.17	0.00	0.04
Sablefish	0.84	0.72	0.72	0.77	0.55	0.78	0.54	0.66	0.52	0.25	0.27	0.22
Shallow-water flatfish	0.43	0.00	0.00	0.87	0.00	0.97	0.00	1.00	0.74	0.28		1.00
Unknown	0.01					1.00	1.00	1.00		1.00		
Grand Total	0.03	0.03	0.04	0.02	0.03	0.02	0.03	0.01	0.02	0.00	0.02	0.02

Table 2.4--Catch of Pacific cod by year, gear, and period as used in the stock assessment model. Jig catches have been merged with longline catches. Catch for 2003 is complete through October.

Year	Trawl			Longline			Pot		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
1978	0	0	4547	0	0	6800	0	0	0
1979	0	0	3629	0	0	9545	0	0	0
1980	0	0	6464	0	0	27780	0	0	0
1981	387	3532	6565	10504	5312	9656	0	0	0
1982	1143	2041	3495	9912	2890	9865	0	0	0
1983	2861	2844	3807	10960	4651	11145	0	0	0
1984	3429	2008	3368	11840	425	2579	0	0	0
1985	2427	571	1878	9127	6	278	0	0	2
1986	2999	431	3420	15922	401	1296	5	59	77
1987	5377	7928	9181	5343	983	1935	219	141	282
1988	16021	6569	4555	2979	507	447	1081	23	318
1989	24614	12857	166	2378	356	928	241	103	32
1990	43279	7514	8395	5557	109	253	2577	1008	2076
1991	55977	631	1484	7296	332	142	9591	0	873
1992	51911	1189	1494	12946	802	2251	9672	14	468
1993	33632	2624	1550	8485	307	181	9689	18	0
1994	29152	1421	873	6696	48	133	8742	0	418
1995	38476	802	2597	10662	166	227	15419	43	592
1996	41450	3048	1493	9991	152	106	12014	27	0
1997	40727	1638	6040	10931	967	424	14007	475	1807
1998	34690	3679	3200	10566	510	280	18479	0	1119
1999	30124	1501	5542	12782	555	191	25167	3374	2548
2000	22133	2574	750	12758	436	169	26947	154	638
2001	15234	2035	7113	11199	662	291	13047	37	1923
2002	15829	2705	1276	12963	259	3334	13602	83	4431
2003	10905	2457	5165	11959	336	759	17711	0	2982

Table 2.5--Pacific cod length sample sizes from the commercial fisheries.

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0	0	634	0	0	18670	0	0	0
1979	0	0	0	0	0	14460	0	0	0
1980	0	0	783	0	0	18671	0	0	0
1981	0	0	461	0	0	19308	0	0	0
1982	0	0	1390	0	0	22856	0	0	0
1983	0	0	2896	0	0	127992	0	0	0
1984	0	0	1039	0	0	47485	0	0	0
1985	0	0	0	0	0	10141	0	0	0
1986	0	0	0	0	0	87304	0	0	0
1987	0	0	0	0	0	387	0	0	0
1988	0	0	0	0	0	2432	0	0	0
1989	660	0	312	0	0	0	0	0	0
1990	25396	10892	12025	9925	0	0	2783	2920	10711
1991	38514	0	131	12551	143	0	49453	139	0
1992	39683	0	2255	28817	577	3603	37177	664	5013
1993	26844	0	0	11748	0	0	20866	0	0
1994	12579	0	0	5201	0	0	16342	0	217
1995	26039	120	2402	24635	0	0	46625	0	1233
1996	17858	0	0	14706	0	0	35256	432	0
1997	22822	225	3746	7239	119	154	26880	252	1537
1998	52448	3465	6763	7981	410	148	31569	291	2902
1999	11550	232	1101	9013	86	396	33876	3719	3656
2000	6951	425	69	11426	47	20	28991	902	277
2001	6115	665	4560	12642	145	141	23290	0	3925
2002	6285	808	309	9583	134	3009	17235	0	4674
2003	4129	1030	971	7941	353	0	12004	0	843

Table 2.6–Length frequencies of Pacific cod in the pre-1987 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	3	0	0	0	0	0	1	1	5	9	5	4	14	40	93	125	106	106	59	39	23	3	1	0	0	0
1980	3	0	0	0	0	0	0	1	0	0	0	1	6	60	162	96	71	91	134	93	48	17	3	0	0	0
1981	3	0	0	0	0	0	0	0	0	0	0	5	29	85	148	145	47	2	0	0	0	0	0	0	0	0
1982	3	0	0	0	0	0	0	0	0	1	3	26	39	118	255	280	294	174	111	52	14	15	5	2	1	0
1983	3	0	0	0	0	0	0	1	2	1	11	24	106	332	388	403	439	375	310	252	143	76	23	7	3	0
1984	3	0	0	0	0	0	0	0	0	1	7	49	135	265	127	140	122	70	47	23	19	13	10	6	4	1

Table 2.7–Length frequencies of Pacific cod in the pre-1987 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1978	3	0	0	0	0	0	0	0	0	7	38	91	276	1160	2235	3077	4051	3359	2139	1261	696	224	49	6	1	0
1979	3	0	0	0	0	0	0	1	6	35	113	285	475	1124	1327	1744	2148	2534	2258	1401	651	271	75	12	0	0
1980	3	0	0	0	0	0	0	0	1	2	43	256	1184	3776	3199	1989	1555	1854	1998	1630	787	276	99	19	2	1
1981	3	0	0	0	0	0	0	0	0	9	29	83	263	1558	4685	5824	3243	1485	844	570	379	199	101	28	8	0
1982	3	0	0	0	0	0	0	0	5	40	106	280	498	1945	3992	5101	4586	3115	1729	815	351	181	80	26	6	0
1983	3	0	0	0	0	0	0	0	3	24	164	728	2661	11515	21037	24663	22224	17602	13130	7842	3868	1638	588	234	63	8
1984	3	0	0	0	0	0	1	1	5	40	135	341	885	4389	9372	10579	7666	4722	3612	2572	1666	958	380	134	23	4
1985	3	0	0	0	0	1	0	8	45	114	206	316	440	1036	990	1847	2170	1294	626	462	294	186	89	14	3	0
1986	3	0	0	0	0	0	0	0	10	133	387	487	681	2963	6979	11599	12075	10988	13158	12084	7943	4112	2254	1025	346	80

Table 2.8a–Length frequencies of Pacific cod in the 1987-1999 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1989	1	0	0	0	0	0	0	0	0	0	0	0	0	5	52	175	248	141	30	5	3	1	0	0	0	0
1989	3	0	0	0	0	0	6	28	41	29	17	3	3	16	37	50	39	14	4	6	2	7	4	4	2	0
1990	1	1	0	1	1	12	7	15	76	119	160	201	228	574	1322	3188	4903	4680	3357	2562	1572	1311	754	256	70	26
1990	2	41	36	15	0	0	1	0	1	3	31	81	169	419	954	1892	2562	2555	1323	510	181	90	24	3	0	1
1990	3	0	0	0	1	2	0	7	13	39	62	180	427	1447	1239	1240	1744	1726	1269	1101	860	434	133	67	18	16
1991	1	0	1	2	2	2	7	63	142	163	226	235	346	1905	3794	4421	5618	6609	5126	3629	2613	1621	1016	618	273	82
1991	3	0	0	0	0	0	0	0	0	0	0	0	0	2	5	15	15	24	28	24	6	9	3	0	0	0
1992	1	0	0	0	1	4	13	21	78	261	567	921	1084	1796	3160	4966	6796	5825	4257	3355	2548	1734	1143	749	280	124
1992	3	0	0	0	0	0	1	8	21	18	7	64	214	479	502	415	211	145	77	63	28	2	0	0	0	0
1993	1	0	0	1	4	2	5	4	58	234	469	547	544	2077	3445	3613	4744	4817	2832	1430	846	491	345	214	87	35
1994	1	0	0	0	0	0	0	0	7	31	83	115	138	499	1022	1734	2551	2642	1659	944	490	347	167	82	44	24
1995	1	0	0	0	0	0	0	1	8	60	91	204	316	1000	2363	3475	4628	5820	4040	1903	993	533	300	164	74	66
1995	2	0	0	0	0	0	1	1	0	0	1	1	9	26	15	20	19	19	6	2	0	0	0	0	0	0
1995	3	0	0	0	0	0	1	14	14	16	14	12	7	51	140	222	583	642	470	153	50	9	3	1	0	0
1996	1	0	0	0	1	6	28	39	64	105	187	250	230	290	690	1575	2924	3744	2948	1949	1237	793	437	217	96	48
1997	1	0	0	3	8	12	12	5	44	123	300	357	276	807	2271	2841	2945	4449	3874	2247	1140	562	288	174	67	17
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	9	28	54	78	46	8	1	0	0	0	0
1997	3	0	0	0	1	3	8	29	49	100	62	56	96	318	374	477	823	589	342	262	100	46	10	1	0	0
1998	1	0	0	0	1	5	7	9	57	293	746	989	832	2009	4345	5676	9100	10443	8205	4970	2379	1278	652	327	98	27
1998	2	0	0	1	3	0	0	1	1	0	2	13	49	196	310	656	854	720	419	148	60	26	1	4	0	1
1998	3	3	4	0	0	5	35	112	133	209	209	146	225	1027	1139	906	1048	747	438	214	112	45	4	1	1	0
1999	1	0	0	1	4	4	4	4	21	73	144	184	215	453	1052	1797	2194	2226	1644	851	397	173	61	30	14	4
1999	2	0	0	0	0	0	5	0	0	0	0	0	1	5	8	34	52	65	36	18	6	2	0	0	0	0
1999	3	0	0	0	0	0	1	0	2	3	6	2	9	14	31	59	271	281	213	124	54	19	10	2	0	0

Table 2.8b–Length frequencies of Pacific cod in the post-1999 trawl fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	2	10	29	74	84	99	250	787	1091	1429	1310	806	475	243	163	72	20	6	1
2000	2	0	0	0	0	0	0	0	3	1	0	9	21	31	30	56	88	100	48	20	14	4	0	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	2	6	13	11	7	6	9	9	5	1	0	0	0	0	0
2001	1	0	1	2	2	1	1	4	7	37	97	158	146	287	694	947	1166	1183	803	336	147	63	22	8	1	2
2001	2	0	0	0	0	0	5	5	5	2	6	18	48	45	68	144	147	99	31	20	16	6	0	0	0	0
2001	3	0	0	0	0	1	0	10	45	100	154	123	80	303	633	669	783	677	496	301	122	46	14	3	0	0
2002	1	0	0	0	0	1	3	5	7	36	118	232	298	497	441	756	975	1123	936	508	218	80	36	8	5	2
2002	2	0	0	0	0	0	0	0	1	3	1	5	24	145	195	101	114	117	55	24	19	3	1	0	0	0
2002	3	0	0	0	0	0	0	0	3	4	6	12	14	36	39	49	51	37	21	12	12	8	4	1	0	0
2003	1	0	0	0	0	0	1	4	13	34	99	150	130	214	609	963	645	433	358	221	133	85	20	10	6	1
2003	2	0	0	0	2	1	2	10	8	7	18	27	53	153	130	149	198	117	93	34	21	5	1	1	0	0
2003	3	0	0	0	0	0	0	1	0	1	1	7	23	99	160	168	229	144	88	29	15	3	3	0	0	0

Table 2.9a–Length frequencies of Pacific cod in the 1987-1999 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1987	3	0	0	0	0	0	0	0	1	1	4	9	17	49	102	109	72	15	6	0	1	1	0	0	0	0
1988	3	0	0	0	0	0	0	0	1	2	17	58	76	252	580	662	412	165	115	39	27	13	3	6	1	3
1990	1	0	0	0	0	0	0	2	2	6	28	82	57	219	511	991	1633	1999	1535	1173	850	549	186	69	30	3
1991	1	0	0	0	0	0	0	0	1	3	8	56	155	670	1351	1839	2473	2486	1740	909	411	229	119	49	23	29
1991	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	16	34	50	22	12	4	1	0	3	0	0
1992	1	0	0	0	0	0	2	3	8	20	57	137	333	1078	2326	4103	5900	4910	3817	2585	1598	906	580	306	103	45
1992	2	0	0	0	0	0	0	0	0	1	2	6	8	13	76	84	119	145	71	28	11	11	2	0	0	0
1992	3	0	0	0	0	0	0	0	1	2	0	11	7	68	185	466	986	1130	541	142	43	15	1	2	2	1
1993	1	0	0	0	1	3	6	9	5	8	18	43	67	357	924	1503	2077	1959	1226	1036	947	856	413	163	75	52
1994	1	0	0	0	0	0	0	0	0	0	1	4	20	166	500	630	1000	1065	788	450	213	167	93	61	26	17
1995	1	0	0	0	0	1	0	3	2	3	24	96	173	692	1662	2521	4264	5252	4025	2628	1606	874	421	212	117	59
1996	1	0	0	0	0	0	0	1	4	21	42	54	79	260	516	1268	2763	3858	3178	1627	583	265	109	48	26	4
1997	1	0	0	0	0	0	0	0	0	3	3	10	12	159	559	925	1267	1575	1431	791	317	118	46	16	6	1
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	0	4	19	27	24	28	15	2	0	0	0	0	0
1997	3	0	0	0	0	0	0	0	0	1	0	1	7	34	17	30	41	12	5	5	1	0	0	0	0	0
1998	1	0	0	0	0	0	0	0	0	2	9	18	53	277	748	1015	1458	1548	1197	833	473	243	78	27	2	0
1998	2	0	0	0	0	0	0	0	0	0	0	0	0	7	28	34	80	116	79	48	8	6	3	0	1	0
1998	3	0	0	0	0	0	0	0	0	0	0	1	0	0	6	18	29	35	38	12	7	1	1	0	0	0
1999	1	0	0	0	0	0	0	0	0	3	6	20	60	254	707	1385	1802	1679	1243	881	474	268	132	62	22	15
1999	2	0	0	0	0	0	0	0	0	0	0	0	0	0	21	36	15	8	6	0	0	0	0	0	0	0
1999	3	0	0	0	0	0	0	0	0	0	0	0	1	17	26	58	67	99	53	48	12	9	1	3	2	0

Table 2.9b–Length frequencies of Pacific cod in the post-1999 longline fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	0	0	1	2	3	2	25	197	797	1697	2548	2714	1747	946	422	179	97	36	10	3
2000	2	0	0	0	0	0	0	0	0	0	0	1	1	1	7	11	13	9	3	1	0	0	0	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	10	2	0	0	0	0	0	0	0	0
2001	1	0	0	0	0	0	0	1	1	3	6	33	82	296	915	1969	2850	3074	1919	906	358	126	60	34	6	3
2001	2	0	0	0	0	0	0	0	0	0	0	1	4	3	9	8	24	43	18	14	12	6	2	1	0	0
2001	3	0	0	0	0	0	0	0	0	0	0	0	0	1	13	13	27	35	28	18	3	1	1	1	0	0
2002	1	0	0	0	0	1	0	0	5	3	13	32	77	246	542	1250	1849	2208	1712	939	447	161	69	21	7	1
2002	2	0	0	0	0	0	0	0	0	0	0	0	2	2	7	18	21	24	23	22	8	3	3	0	1	0
2002	3	0	0	0	0	1	2	9	24	16	16	18	38	103	279	424	618	622	440	263	95	31	8	0	2	0
2003	1	0	0	0	0	0	0	0	0	5	7	30	92	385	800	1337	1415	1523	1097	626	382	149	58	26	9	0
2003	2	0	0	0	0	0	0	0	0	0	1	3	1	5	16	45	47	74	53	41	34	25	7	0	1	0

Table 2.10a–Length frequencies of Pacific cod in the 1987-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1990	1	0	0	0	0	0	0	0	0	0	0	0	0	30	141	351	679	766	426	208	76	54	33	12	6	1
1990	2	0	0	0	0	0	0	0	0	0	0	1	3	39	144	525	845	748	382	151	62	14	3	2	1	0
1990	3	0	0	0	0	0	0	0	0	0	2	42	167	438	630	1172	1994	2355	1732	1139	579	313	123	23	2	0
1991	1	0	0	0	0	0	0	0	1	2	16	44	87	799	2413	5253	11348	13970	9321	4071	1403	487	180	49	8	1
1991	2	0	0	0	0	0	0	0	0	0	0	0	0	1	8	11	23	31	45	11	6	2	1	0	0	0
1992	1	0	0	0	0	0	0	0	1	10	29	58	148	700	2092	5494	9467	9042	5461	2671	1248	509	190	45	11	1
1992	2	0	0	0	0	0	0	0	0	0	0	0	1	10	45	81	118	164	118	71	34	12	5	4	0	1
1992	3	0	0	0	0	0	0	0	0	0	1	7	24	91	191	489	1073	1337	898	545	222	93	35	7	0	0
1993	1	0	0	0	0	0	0	0	0	0	0	13	51	319	1173	2529	4897	5815	3641	1546	566	201	78	28	7	2
1994	1	0	0	0	0	0	0	0	0	0	0	3	26	196	943	2218	4052	4217	2759	1228	428	160	71	28	13	0
1994	3	0	0	0	0	0	0	0	0	0	0	0	1	16	59	56	32	19	14	6	4	2	4	2	2	0
1995	1	0	0	0	0	0	0	0	0	1	4	12	33	607	2329	4778	9405	12541	8610	4502	2120	1026	403	170	59	25
1995	3	0	0	0	0	0	0	0	0	0	0	0	0	8	51	200	394	274	152	74	40	26	8	5	1	0
1996	1	0	0	0	0	0	0	0	2	4	6	5	23	174	954	3199	6690	9720	8399	3889	1431	489	184	67	15	5
1996	2	0	0	0	0	0	0	0	0	0	0	0	0	7	24	105	130	55	36	31	20	12	8	1	2	1
1997	1	6	0	1	1	4	9	12	18	43	45	43	53	263	969	2843	6289	7541	5200	2299	750	268	151	50	19	3
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	84	82	38	9	5	2	1	0	0	0
1997	3	0	0	0	0	0	0	0	0	0	0	0	4	18	46	90	228	440	390	206	64	29	16	5	1	0
1998	1	0	0	0	0	0	0	0	2	0	1	14	19	281	1081	2513	6362	8088	6459	4003	1699	660	257	97	24	9
1998	2	0	0	0	0	0	0	0	0	0	0	0	0	1	9	31	51	60	64	38	15	11	7	3	0	1
1998	3	0	0	0	0	0	0	0	3	2	7	7	9	62	126	259	477	623	640	362	184	74	33	15	18	1
1999	1	0	0	0	0	0	0	0	0	1	1	15	51	392	1769	4157	7042	8712	6480	2980	1313	586	216	102	42	17
1999	2	0	0	0	0	0	0	0	0	0	0	0	0	7	56	317	653	720	838	626	306	131	48	11	5	1
1999	3	0	0	0	1	0	0	0	1	0	1	0	8	65	188	402	824	858	648	339	166	75	48	24	6	2

Table 2.10b–Length frequencies of Pacific cod in the post-1999 pot fishery by year, period, and length bin.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2000	1	0	0	0	0	0	3	2		3	1	9	41	464	1839	3998	6894	6987	4694	2237	1055	454	203	73	25	9
2000	2	0	0	0	0	0	0	0	0	0	0	0	0	1	7	76	374	316	104	17	5	0	2	0	0	0
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	3	7	17	73	105	55	13	2	1	1	0	0	0
2001	1	1	0	0	0	0	0	0	1	0	4	13	62	310	1339	3324	6205	6366	3540	1202	525	222	106	49	16	5
2001	3	0	0	0	0	0	0	0	0	0	0	3	10	104	389	730	956	954	553	134	56	26	3	4	1	2
2002	1	0	0	0	0	0	0	0	0	0	0	15	39	323	1192	2507	3864	4315	3048	1245	427	159	68	24	8	1
2002	3	0	0	0	0	0	0	0	1	0	2	2	17	133	312	580	926	982	841	479	217	106	53	16	6	1
2003	1	0	0	0	0	0	1	0	2	3	9	46	82	369	1203	2049	2561	2267	1750	945	442	167	63	28	14	3
2003	3	0	0	0	0	0	0	0	0	0	0	0	2	29	109	143	179	142	139	59	28	6	5	2	0	0

Table 2.11–Length frequencies of Pacific cod in the trawl survey by year (all surveys take place in period 2). Numbers shown are survey estimates of population numbers at length, rescaled so that the sum equals the total size of the actual survey length sample.

		Length Bin																								
Yr.	Per	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1984	2	174	34	34	121	104	87	104	469	992	1479	1653	1096	1566	3046	2576	1897	1131	469	226	69	52	17	17	0	0
1987	2	450	19	19	39	98	254	490	529	705	666	1234	1411	2822	4076	3116	1724	842	333	333	254	117	39	19	0	0
1990	2	251	0	11	103	217	137	57	114	240	286	435	549	1602	1774	1969	1683	973	549	194	160	80	34	11	11	0
1993	2	0	17	188	325	239	291	205	256	462	548	839	1318	2055	2620	3134	2055	1404	650	274	119	68	34	17	17	17
1996	2	0	35	232	875	1191	903	244	84	193	303	446	445	712	1043	1389	1668	1403	608	228	87	41	30	15	13	2
1999	2	1	17	68	154	166	97	75	142	310	352	402	582	1093	1142	1448	1208	793	416	168	11	0	0	0	0	0
2001	2	5	58	105	193	233	319	228	186	182	310	455	435	749	753	725	767	536	304	135	52	18	14	5	5	0
2003	2	0	5	28	76	137	88	66	65	160	297	500	755	1282	1315	1622	1306	698	371	190	112	36	15	3	0	0

Table 2.12--Biomass, standard error, 95% confidence interval (CI), and population numbers of Pacific cod estimated by NMFS' triennial bottom trawl survey of the GOA. All figures except population numbers are expressed in metric tons. Population numbers are expressed in terms of individual fish.

Year	Biomass	Standard Error	Lower 95% CI	Upper 95% CI	Numbers
1984	550,971	80,385	393,417	708,525	321,950,465
1987	394,987	51,325	294,390	495,585	247,020,039
1990	418,200	63,757	293,236	543,164	212,131,668
1993	409,848	73,431	265,924	553,772	232,582,993
1996	538,154	107,736	326,991	749,316	319,068,011
1999	306,413	38,699	230,563	382,263	166,583,892
2001	279,332	62,031	157,751	400,912	168,424,041
2003	297,361	44,514	210,114	384,608	160,179,554

Note: The 2001 survey did not cover the eastern GOA. To account for the missing stations, the 1999 survey estimates of biomass, biomass variance, and numbers for the eastern GOA were added to the respective 2001values to produce the figures shown in the above table.

Table 2.13–Symbols used in the Synthesis assessment model for Pacific cod (page 1 of 2).

Indices	
a	age group
g	gear type
i	time interval
j	size bin
y	year

Dimensions	
a_{min}	age of youngest group
a_{max}	age of oldest group
g_{max}	number of gear types
i_{max}	number of time intervals in each year
j_{max}	number of size bins
y_{max}	number of years

Special Values of Indices	
a_{rec}	index of age group used to assess recruitment strength
g_{sur}	index of survey gear type
i_{spa}	index of time interval during which spawning occurs
i_{sur}	index of time interval during which survey occurs

Operators	
$e(y\|g)$	returns the era containing year y given gear type g
l_{mid}	returns the length corresponding to the midpoint of bin j
l_{min}	returns the smallest length contained in bin j
t_{dur}	returns the duration (in years) of time interval i

Continuous Variables	
α	age
λ	length
τ	time

Special Values of Continuous Variables	
α_1	first reference age used in length-at-age relationship (in years)
α_2	second reference age used in length-at-age relationship (in years)
λ_{min}	minimum length used in assessment
λ_{max}	maximum length used in assessment
τ_{spa}	annual time of spawning (in years)
τ_{sur}	annual time of survey (in years)

Table 2.13–Symbols used in the Synthesis assessment model for Pacific cod (page 2 of 2).

Functions of Age or Length

$h(\lambda\|\alpha)$	probability density function describing distribution of length, conditional on age
$l(\alpha)$	length at age
$p(\lambda)$	proportion mature at length
$s(\lambda\|g,y)$	selectivity at length, conditional on gear type and year
$w(\lambda)$	weight at length
$x(\alpha)$	standard deviation associated with the length-at-age relationship, as a function of age

Arrays Generated by Synthesis

b_y	biomass of population aged $a \geq a_{rec}$ at start of year y
c_y	spawning biomass at time of spawning in year y
d_y	survey biomass at time of survey in year y
$n_{a,y,i}$	population numbers at age a, year y, and time interval i
$u_{a,y}$	population numbers at time of spawning at age a and year y
$v_{a,y}$	population numbers at time of survey at age a and year y
$z_{a,i,j}$	proportion of length distribution falling within size bin j at age a and time interval i

Parameters Used by Synthesis

$F_{g,y,i}$	instantaneous fishing mortality rate at each gear g, year y, and time i for which catch>0
K	Brody's growth parameter
L_1	length at age α_1
L_2	length at age α_2
M	instantaneous natural mortality rate
N_a	initial population numbers at each age $a > a_{min}$
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
R_y	recruitment at age a_{min} in year y
$S_{1,g,e(y\|g)}$	selectivity at minimum length in gear type g and era e
$S_{2,g,e(y\|g)}$	length at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{3,g,e(y\|g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type g and era e
$S_{4,g,e(y\|g)}$	length at maximum selectivity in gear type g and era e
$S_{5,g,e(y\|g)}$	selectivity at maximum length in gear type g and era e
$S_{6,g,e(y\|g)}$	length at inflection in descending part of selectivity schedule in gear type g and era e
$S_{7,g,e(y\|g)}$	relative slope at inflection in descending part of selectivity schedule in gear type g and era e
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Table 2.14–Dimensions and special values of indices and variables used in the Pacific cod assessment. Symbols are defined in Table 2.13.

Dimensions

Term	Value	Comments/Rationale
a_{min}	1	assumed minimum age group observed in the trawl survey
a_{max}	12	a convenient place to insert an "age-plus" category
g_{max}	5	early trawl, late trawl, longline, pot, survey
i_{max}	3	January through March, June through August, September through December
j_{max}	25	bin boundaries are given in the "Data" section of the text
y_{max}	26	1978 through 2003

Special Values of Indices

Term	Value	Comments/Rationale
a_{rec}	3	age traditionally used to indicate first significant recruitment to the fishery
g_{sur}	5	index of survey gear type
i_{spa}	1	March (see τ_{spa} below) falls within the first intra-annual time period
i_{sur}	2	July (see τ_{sur} below) falls within the second intra-annual time period

Special Values of Continuous Variables

Term	Value	Comments/Rationale
α_1	1.5	assumed age of youngest fish seen in the trawl survey
α_2	12.0	set equal to the lower bound of the age-plus group for convenience
λ_{min}	9	close to the length of the smallest fish seen by the survey in a typical year
λ_{max}	115	close to the length of the largest fish seen by the survey in a typical year
τ_{spa}	3/12	March appears to be the month of peak spawning in the observer data
τ_{sur}	7/12	July is the approximate mid-point of the June-August trawl survey season

Table 2.15–Partitioning the list of parameters used in the Synthesis model of Pacific cod into those that are estimated independently (i.e., outside) of Synthesis and those that are estimated conditionally (i.e., inside of Synthesis).

Parameters Estimated Independently	
L_1	length at age α_1
M	instantaneous natural mortality rate
P_1	length at point of inflection in maturity schedule
P_2	relative slope at point of inflection in maturity schedule
Q	survey catchability
W_1	weight-length proportionality
W_2	weight-length exponent
X_1	standard deviation of length evaluated at age α_1
X_2	standard deviation of length evaluated at age α_2

Parameters Estimated Conditionally	
$F_{g,y,i}$	instantaneous fishing mortality rate at each gear *g*, year *y*, and time *i* for which catch>0
K	Brody's growth parameter
L_2	length at age α_2
N_a	initial population numbers at each age $a > a_{min}$
R_y	recruitment at age a_{min} in year *y*
$S_{1,g,e(y\|g)}$	selectivity at minimum length in gear type *g* and era *e*
$S_{2,g,e(y\|g)}$	length at inflection in ascending part of selectivity schedule in gear type *g* and era *e*
$S_{3,g,e(y\|g)}$	relative slope at inflection in ascending part of selectivity schedule in gear type *g* and era *e*
$S_{4,g,e(y\|g)}$	length at maximum selectivity in gear type *g* and era *e*
$S_{5,g,e(y\|g)}$	selectivity at maximum length in gear type *g* and era *e*
$S_{6,g,e(y\|g)}$	length at inflection in descending part of selectivity schedule in gear type *g* and era *e*
$S_{7,g,e(y\|g)}$	relative slope at inflection in descending part of selectivity schedule in gear type *g* and era *e*

Table 2.16–Pacific cod commercial fishery length sample sizes used in the multinomial distribution. (These values correspond to the square roots of the true sample sizes shown in Table 2.5.)

Year	Trawl Fishery			Longline Fishery			Pot Fishery		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978	0	0	25	0	0	137	0	0	0
1979	0	0	0	0	0	120	0	0	0
1980	0	0	28	0	0	137	0	0	0
1981	0	0	21	0	0	139	0	0	0
1982	0	0	37	0	0	151	0	0	0
1983	0	0	54	0	0	358	0	0	0
1984	0	0	32	0	0	218	0	0	0
1985	0	0	0	0	0	101	0	0	0
1986	0	0	0	0	0	295	0	0	0
1987	0	0	0	0	0	20	0	0	0
1988	0	0	0	0	0	49	0	0	0
1989	26	0	18	0	0	0	0	0	0
1990	159	104	110	100	0	0	53	54	103
1991	196	0	11	112	12	0	222	12	0
1992	199	0	47	170	24	60	193	26	71
1993	164	0	0	108	0	0	144	0	0
1994	112	0	0	72	0	0	128	0	15
1995	161	11	49	157	0	0	216	0	35
1996	134	0	0	121	0	0	188	21	0
1997	151	15	61	85	11	12	164	16	39
1998	229	59	82	89	20	12	178	17	54
1999	107	15	33	95	9	20	184	61	60
2000	83	21	8	107	7	4	170	30	17
2001	78	26	68	112	12	12	153	0	63
2002	79	28	18	98	12	55	131	0	68
2003	64	32	31	89	19	0	110	0	29

Table 2.17–Estimates of Pacific cod fishing mortality rates, expressed on an annual time scale. Empty cells indicate that no catch was recorded.

Year	Trawl			Longline			Pot		
	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3	Per. 1	Per. 2	Per. 3
1978			0.04			0.06			
1979			0.03			0.08			
1980			0.04			0.20			
1981	0.00	0.03	0.04	0.06	0.05	0.06			
1982	0.01	0.01	0.02	0.05	0.02	0.06			
1983	0.02	0.02	0.02	0.05	0.03	0.06			
1984	0.02	0.01	0.02	0.05	0.00	0.01			
1985	0.02	0.00	0.01	0.04	0.00	0.00			
1986	0.02	0.00	0.02	0.07	0.00	0.01			
1987	0.03	0.08	0.07	0.03	0.01	0.01	0.00	0.00	0.00
1988	0.09	0.07	0.04	0.02	0.00	0.00	0.01	0.00	0.00
1989	0.13	0.13	0.00	0.01	0.00	0.01	0.00	0.00	0.00
1990	0.23	0.08	0.07	0.03	0.00	0.00	0.02	0.01	0.02
1991	0.32	0.01	0.01	0.04	0.00	0.00	0.08		0.01
1992	0.31	0.01	0.01	0.08	0.01	0.02	0.08	0.00	0.00
1993	0.20	0.03	0.01	0.05	0.00	0.00	0.08	0.00	
1994	0.17	0.01	0.01	0.04	0.00	0.00	0.07		0.00
1995	0.22	0.01	0.02	0.06	0.00	0.00	0.12	0.00	0.01
1996	0.24	0.03	0.01	0.06	0.00	0.00	0.09	0.00	
1997	0.25	0.02	0.05	0.07	0.01	0.00	0.12	0.01	0.02
1998	0.23	0.05	0.03	0.07	0.01	0.00	0.17		0.01
1999	0.21	0.02	0.06	0.09	0.01	0.00	0.25	0.06	0.03
2000	0.15	0.03	0.01	0.11	0.01	0.00	0.24	0.00	0.01
2001	0.10	0.02	0.07	0.10	0.01	0.00	0.12	0.00	0.02
2002	0.12	0.04	0.01	0.12	0.00	0.04	0.14	0.00	0.06
2003	0.08	0.03	0.05	0.12	0.01	0.01	0.20		0.04

Table 2.18–Estimates of Pacific cod recruitment at age 1 and initial numbers at age (in millions of fish).

Year	Recruitment at 1
1978	498
1979	207
1980	347
1981	297
1982	266
1983	209
1984	298
1985	401
1986	265
1987	289
1988	377
1989	301
1990	405
1991	313
1992	263
1993	242
1994	248
1995	292
1996	311
1997	194
1998	161
1999	224
2000	233
2001	235
2002	71
2003	76

Age	Numbers at age
2	247
3	47
4	52
5	31
6	70
7	0
8	20
9	9
10	0
11	1
12	0

Table 2.19–Estimates of Pacific cod selectivity parameters. The first column lists the parameter families for which the remaining columns contain era-specific estimates.

Trawl (Jan-May)	1978-86	1987-99	2000-03
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	63.73	57.97
$S_{3,g,e(y\|g)}$	n/a	0.19	0.20
$S_{4,g,e(y\|g)}$	n/a	114.05	96.13
$S_{5,g,e(y\|g)}$	n/a	1.00	0.30
$S_{6,g,e(y\|g)}$	n/a	114.14	99.51
$S_{7,g,e(y\|g)}$	n/a	0.17	1.05
Trawl (Jun-Dec)	1978-86	1987-99	2000-03
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	50.42	64.26	55.80
$S_{3,g,e(y\|g)}$	0.35	0.16	0.20
$S_{4,g,e(y\|g)}$	96.03	73.55	67.94
$S_{5,g,e(y\|g)}$	0.83	0.24	0.50
$S_{6,g,e(y\|g)}$	96.03	84.99	80.74
$S_{7,g,e(y\|g)}$	8.92	0.16	0.36
Longline	1978-86	1987-99	2000-03
$S_{1,g,e(y\|g)}$	0.00	0.00	0.00
$S_{2,g,e(y\|g)}$	53.56	62.43	62.62
$S_{3,g,e(y\|g)}$	0.33	0.25	0.26
$S_{4,g,e(y\|g)}$	80.76	93.27	78.64
$S_{5,g,e(y\|g)}$	0.88	0.81	0.22
$S_{6,g,e(y\|g)}$	109.59	94.20	79.62
$S_{7,g,e(y\|g)}$	9.89	0.92	0.11
Pot	1978-86	1987-99	2000-03
$S_{1,g,e(y\|g)}$	n/a	0.00	0.00
$S_{2,g,e(y\|g)}$	n/a	66.15	61.39
$S_{3,g,e(y\|g)}$	n/a	0.28	0.29
$S_{4,g,e(y\|g)}$	n/a	76.31	75.99
$S_{5,g,e(y\|g)}$	n/a	0.20	0.20
$S_{6,g,e(y\|g)}$	n/a	76.31	75.99
$S_{7,g,e(y\|g)}$	n/a	0.13	0.19
Survey	1984-03		
$S_{1,g,e(y\|g)}$	0.06		
$S_{2,g,e(y\|g)}$	54.48		
$S_{3,g,e(y\|g)}$	0.15		
$S_{4,g,e(y\|g)}$	62.32		
$S_{5,g,e(y\|g)}$	0.23		
$S_{6,g,e(y\|g)}$	75.65		
$S_{7,g,e(y\|g)}$	0.25		

Table 2.20–Time series of GOA Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated by the assessment model. The biomass time series obtained by the survey is shown in the right-hand column for comparison. All biomass figures are in 1000s of t.

Year	Age 3+	Spawning	Survey (est)	Survey (obs)
1978	443	89		
1979	501	103		
1980	610	113		
1981	636	118		
1982	682	128		
1983	713	141		
1984	727	154	438	551
1985	723	165		
1986	735	174		
1987	773	177	424	395
1988	775	176		
1989	778	177		
1990	781	172	444	418
1991	752	162		
1992	757	153		
1993	757	150	453	410
1994	754	154		
1995	732	159		
1996	695	157	402	538
1997	669	150		
1998	649	139		
1999	609	129	352	306
2000	551	120		
2001	528	118	306	279
2002	512	113		
2003	501	106	278	297

Table 2.21–Distribution of Pacific cod lengths (in cm) at age (mid-year) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins. Columns sum to 1.0.

Len.	Age Group											
	1	2	3	4	5	6	7	8	9	10	11	12+
105	0	0	0	0	0	0	0	0	0	0	0	0.028
100	0	0	0	0	0	0	0	0	0	0	0.003	0.069
95	0	0	0	0	0	0	0	0	0.001	0.006	0.026	0.150
90	0	0	0	0	0	0	0	0.001	0.010	0.048	0.122	0.225
85	0	0	0	0	0	0	0	0.012	0.074	0.186	0.283	0.235
80	0	0	0	0	0	0	0.011	0.093	0.244	0.335	0.325	0.170
75	0	0	0	0	0	0.005	0.095	0.287	0.359	0.286	0.184	0.085
70	0	0	0	0	0.001	0.071	0.309	0.367	0.235	0.115	0.051	0.030
65	0	0	0	0	0.030	0.299	0.379	0.194	0.069	0.022	0.007	0.007
60	0	0	0	0.003	0.225	0.411	0.174	0.042	0.009	0.002	0	0.001
55	0	0	0	0.084	0.456	0.185	0.030	0.004	0.001	0	0	0
50	0	0	0.004	0.415	0.250	0.027	0.002	0	0	0	0	0
45	0	0	0.133	0.413	0.037	0.001	0	0	0	0	0	0
42	0	0	0.307	0.071	0.001	0	0	0	0	0	0	0
39	0	0.002	0.348	0.013	0	0	0	0	0	0	0	0
36	0	0.044	0.170	0.001	0	0	0	0	0	0	0	0
33	0	0.262	0.035	0	0	0	0	0	0	0	0	0
30	0	0.444	0.003	0	0	0	0	0	0	0	0	0
27	0	0.217	0	0	0	0	0	0	0	0	0	0
24	0.022	0.030	0	0	0	0	0	0	0	0	0	0
21	0.332	0.001	0	0	0	0	0	0	0	0	0	0
18	0.543	0	0	0	0	0	0	0	0	0	0	0
15	0.101	0	0	0	0	0	0	0	0	0	0	0
12	0.002	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.22–Schedules of Pacific cod weight (kg) and maturity proportions at length (cm) as defined by final parameter estimates. Lengths correspond to lower bounds of size bins.

Bin	Length	Weight	Maturity
1	9	0.010	0
2	12	0.022	0.001
3	15	0.042	0.001
4	18	0.070	0.001
5	21	0.110	0.002
6	24	0.163	0.003
7	27	0.231	0.004
8	30	0.316	0.006
9	33	0.421	0.010
10	36	0.547	0.015
11	39	0.697	0.023
12	42	0.873	0.035
13	45	1.159	0.061
14	50	1.588	0.117
15	55	2.114	0.210
16	60	2.748	0.347
17	65	3.501	0.514
18	70	4.385	0.678
19	75	5.411	0.808
20	80	6.590	0.894
21	85	7.933	0.945
22	90	9.453	0.972
23	95	11.160	0.986
24	100	13.067	0.993
25	105	14.072	0.995

Table 2.23–Schedules of Pacific cod selectivities as defined by final parameter estimates. Lengths (cm) correspond to lower bounds of size bins. Trawl(1) = period 1 (January-May) trawl fishery, Trawl(2-3) = periods 2-3 (June-December) trawl fishery.

Bin	Len.	Trawl (1)		Trawl (2-3)			Longline			Pot		Survey
		87-99	00-03	78-86	87-99	00-03	78-86	87-99	00-03	87-99	00-03	84-03
1	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
2	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
3	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
4	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
5	21	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.08
6	24	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.09
7	27	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.11
8	30	0.01	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.13
9	33	0.01	0.01	0.01	0.03	0.04	0.01	0.00	0.00	0.00	0.00	0.17
10	36	0.02	0.02	0.03	0.04	0.06	0.02	0.01	0.01	0.00	0.00	0.22
11	39	0.03	0.03	0.09	0.06	0.11	0.04	0.01	0.01	0.00	0.01	0.30
12	42	0.05	0.05	0.22	0.10	0.19	0.11	0.03	0.02	0.01	0.02	0.39
13	45	0.09	0.09	0.46	0.15	0.30	0.25	0.06	0.05	0.02	0.05	0.51
14	50	0.20	0.20	0.83	0.29	0.55	0.64	0.18	0.17	0.07	0.19	0.74
15	55	0.39	0.39	0.97	0.50	0.81	0.90	0.43	0.43	0.25	0.50	0.96
16	60	0.63	0.63	0.99	0.75	0.98	0.98	0.73	0.74	0.59	0.82	0.94
17	65	0.81	0.81	1.00	0.97	0.97	1.00	0.90	0.93	0.90	0.97	0.77
18	70	0.92	0.92	1.00	0.90	0.85	1.00	0.97	1.00	0.92	0.86	0.52
19	75	0.97	0.97	1.00	0.72	0.64	1.00	0.99	0.80	0.68	0.56	0.34
20	80	0.99	0.99	1.00	0.54	0.53	1.00	1.00	0.61	0.49	0.36	0.27
21	85	1.00	1.00	1.00	0.40	0.51	1.00	0.90	0.46	0.36	0.27	0.24
22	90	1.00	1.00	0.83	0.31	0.50	1.00	0.81	0.35	0.28	0.23	0.24
23	95	1.00	1.00	0.83	0.27	0.50	1.00	0.81	0.28	0.24	0.21	0.23
24	100	1.00	1.00	0.83	0.25	0.50	0.88	0.81	0.23	0.21	0.20	0.23
25	105	1.00	1.00	0.83	0.24	0.50	0.88	0.81	0.22	0.20	0.20	0.23

Table 2.24–Time series of Pacific cod age 3+ biomass, spawning biomass, and survey biomass as estimated in last year's and this year's assessments.

Year	Age 3+ Biomass		Spawning Biomass		Survey Biomass	
	Last Year	This Year	Last Year	This Year	Last Year	This Year
1978	523	443	104	89		
1979	566	501	119	103		
1980	692	610	129	113		
1981	723	636	134	118		
1982	763	682	144	128		
1983	798	713	156	141		
1984	804	727	169	154	506	438
1985	805	723	178	165		
1986	803	735	185	174		
1987	836	773	188	177	484	424
1988	838	775	185	176		
1989	831	778	185	177		
1990	842	781	178	172	487	444
1991	810	752	166	162		
1992	805	757	156	153		
1993	782	757	150	150	477	453
1994	768	754	152	154		
1995	745	732	153	159		
1996	699	695	148	157	404	402
1997	659	669	139	150		
1998	632	649	126	139		
1999	586	609	115	129	334	352
2000	519	551	103	120		
2001	471	528	99	118	279	306
2002	454	512	92	113		
2003	n/a	501	n/a	106	n/a	278

Notes: Spawning biomass is computed as the sum of March female numbers at age times population weight at age times fraction mature at age.

"Survey biomass" is the model's estimate of what the actual survey should have observed.

All biomass figures are in 1000s of t.

Table 2.25–Time series of Pacific cod age 3 recruitment as estimated in last year's and this year's assessments.

Year	Recruitment (millions of age 3 fish)	
	Last Year	This Year
1978	54	47
1979	140	170
1980	265	237
1981	101	99
1982	156	165
1983	153	141
1984	114	126
1985	120	98
1986	111	140
1987	192	189
1988	127	125
1989	116	138
1990	178	180
1991	128	144
1992	175	193
1993	137	149
1994	116	125
1995	99	115
1996	103	118
1997	111	139
1998	133	148
1999	78	93
2000	64	77
2001	72	107
2002	n/a	111
2003	n/a	112

Table 2.26–Time series of Pacific cod catch divided by age 3+ biomass as estimated in last year's and this year's assessments (the last entry in each column is based on partial catches for the respective year, because the year was/is still in progress at the time of the assessment).

Year	Catch Divided by Age 3+ Biomass	
	Last Year	This Year
1978	0.02	0.03
1979	0.03	0.03
1980	0.05	0.06
1981	0.05	0.06
1982	0.04	0.04
1983	0.05	0.05
1984	0.03	0.03
1985	0.02	0.02
1986	0.03	0.03
1987	0.04	0.04
1988	0.04	0.04
1989	0.05	0.06
1990	0.09	0.09
1991	0.09	0.10
1992	0.10	0.11
1993	0.07	0.07
1994	0.06	0.06
1995	0.09	0.09
1996	0.10	0.10
1997	0.10	0.12
1998	0.10	0.11
1999	0.12	0.13
2000	0.13	0.12
2001	0.11	0.10
2002	0.10	0.11
2003	n/a	0.10

Table 2.27–Definitions of symbols and terms used in the Pacific cod projection tables.

Symbol	Definition
SPR	Equilibrium spawning per recruit, expressed as a percentage of the maximum level
L90%CI	Lower bound of the 90% confidence interval
Median	Point that divides projection outputs into two groups of equal size (50% higher, 50% lower)
Mean	Average value of the projection outputs
U90%CI	Upper bound of the 90% confidence interval
St. Dev.	Standard deviation of the projection outputs

Table 2.28–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2004-2016, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	102.9	102.9	102.9	102.9	0.00
2005	90.5	90.6	90.6	90.7	0.05
2006	78.8	79.2	79.3	80.0	0.38
2007	68.6	70.4	70.7	73.9	1.71
2008	62.0	67.0	67.8	76.1	4.48
2009	60.8	70.6	71.5	84.9	7.83
2010	64.1	76.9	78.1	95.5	10.09
2011	68.3	82.5	83.7	102.7	11.19
2012	71.0	85.4	87.2	107.6	11.82
2013	72.1	87.2	88.8	110.8	12.26
2014	73.5	87.8	89.7	112.2	12.48
2015	74.5	88.1	90.5	113.4	12.60
2016	74.9	88.4	90.9	113.9	12.73

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.34	0.34	0.34	0.34	0.000
2005	0.34	0.34	0.34	0.34	0.000
2006	0.30	0.30	0.30	0.30	0.002
2007	0.26	0.26	0.27	0.28	0.007
2008	0.23	0.25	0.25	0.29	0.018
2009	0.23	0.26	0.27	0.32	0.029
2010	0.24	0.29	0.29	0.34	0.032
2011	0.26	0.31	0.31	0.34	0.029
2012	0.27	0.32	0.32	0.34	0.025
2013	0.27	0.33	0.32	0.34	0.024
2014	0.28	0.33	0.32	0.34	0.022
2015	0.28	0.33	0.32	0.34	0.021
2016	0.28	0.34	0.32	0.34	0.020

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	71.2	71.2	71.2	71.2	0.00
2005	64.4	64.4	64.4	64.4	0.02
2006	48.4	48.9	49.0	49.9	0.48
2007	34.7	37.1	37.6	42.1	2.41
2008	28.7	35.8	37.3	51.2	7.31
2009	29.9	44.2	46.4	69.8	12.99
2010	35.5	55.1	57.2	84.5	15.63
2011	40.7	63.5	64.4	89.2	15.88
2012	44.5	67.1	67.8	93.4	15.59
2013	45.3	69.6	69.2	94.2	15.47
2014	46.7	69.4	69.7	94.2	15.19
2015	47.4	69.7	70.1	94.8	15.04
2016	47.5	69.7	70.3	95.7	15.05

Table 2.29–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that the ratio of F to $max\ F_{ABC}$ in each year 2004-2016 is fixed at a value of 0.87, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	103.4	103.4	103.4	103.4	0.00
2005	93.5	93.5	93.5	93.7	0.05
2006	83.3	83.7	83.8	84.5	0.38
2007	73.1	74.9	75.2	78.4	1.72
2008	66.1	71.1	71.9	80.3	4.53
2009	64.4	74.3	75.3	89.1	8.02
2010	67.4	80.7	82.0	100.3	10.59
2011	71.7	86.6	88.1	109.0	12.09
2012	74.7	90.1	92.2	114.4	13.05
2013	75.8	92.5	94.5	118.9	13.71
2014	77.3	93.9	95.9	121.5	14.06
2015	78.8	94.7	97.2	123.0	14.25
2016	79.5	95.7	98.0	123.5	14.42

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.29	0.29	0.29	0.29	0.000
2005	0.29	0.29	0.29	0.29	0.000
2006	0.27	0.27	0.27	0.28	0.001
2007	0.24	0.24	0.25	0.26	0.006
2008	0.21	0.23	0.23	0.26	0.016
2009	0.21	0.24	0.24	0.29	0.025
2010	0.22	0.26	0.26	0.29	0.026
2011	0.23	0.28	0.28	0.29	0.022
2012	0.24	0.29	0.28	0.29	0.018
2013	0.25	0.29	0.28	0.29	0.016
2014	0.25	0.29	0.29	0.29	0.015
2015	0.26	0.29	0.29	0.29	0.013
2016	0.26	0.29	0.29	0.29	0.012

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	62.8	62.8	62.8	62.8	0.00
2005	58.2	58.2	58.2	58.2	0.02
2006	46.9	47.3	47.4	48.2	0.44
2007	34.1	36.3	36.8	40.9	2.23
2008	28.0	34.6	36.1	48.9	6.74
2009	28.7	41.9	44.0	65.8	11.73
2010	33.8	52.0	53.6	76.6	13.88
2011	38.5	60.3	60.0	81.7	13.97
2012	42.2	63.5	63.4	86.0	13.70
2013	43.1	65.2	64.8	87.1	13.60
2014	45.0	65.3	65.6	87.9	13.36
2015	45.6	65.4	66.1	87.9	13.18
2016	45.5	65.4	66.3	88.7	13.15

Table 2.30–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = ½\ max\ F_{ABC}$ in each year 2004-2016, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	104.9	104.9	104.9	104.9	0.00
2005	102.5	102.6	102.6	102.7	0.05
2006	98.0	98.4	98.5	99.2	0.39
2007	90.2	92.2	92.5	95.9	1.84
2008	82.5	87.9	88.8	98.2	4.98
2009	79.4	90.0	91.4	107.7	9.17
2010	81.4	96.7	98.6	120.7	13.00
2011	85.3	104.4	106.7	133.8	15.81
2012	89.4	111.1	113.7	142.9	17.66
2013	92.2	116.6	118.6	151.0	18.80
2014	95.4	120.3	122.4	156.2	19.38
2015	98.4	124.2	126.0	160.2	19.65
2016	100.7	126.2	128.4	162.5	19.74

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.17	0.17	0.17	0.17	0.000
2005	0.17	0.17	0.17	0.17	0.000
2006	0.17	0.17	0.17	0.17	0.000
2007	0.17	0.17	0.17	0.17	0.000
2008	0.15	0.16	0.16	0.17	0.006
2009	0.15	0.17	0.16	0.17	0.008
2010	0.15	0.17	0.17	0.17	0.006
2011	0.16	0.17	0.17	0.17	0.004
2012	0.17	0.17	0.17	0.17	0.003
2013	0.17	0.17	0.17	0.17	0.002
2014	0.17	0.17	0.17	0.17	0.002
2015	0.17	0.17	0.17	0.17	0.001
2016	0.17	0.17	0.17	0.17	0.001

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	37.5	37.5	37.5	37.5	0.00
2005	37.3	37.3	37.3	37.3	0.01
2006	34.3	34.4	34.5	34.7	0.14
2007	29.3	30.5	30.6	32.5	1.01
2008	24.2	29.1	29.7	36.8	3.98
2009	23.7	33.5	33.5	44.1	6.54
2010	26.7	38.1	38.5	51.8	7.72
2011	30.2	41.6	42.3	56.0	8.15
2012	32.9	43.7	44.8	58.5	8.37
2013	34.1	45.6	46.3	60.9	8.49
2014	35.4	46.3	47.2	61.6	8.47
2015	36.1	46.6	47.8	62.0	8.43
2016	36.5	47.0	48.1	62.5	8.42

Table 2.31–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that *F* = the 1997-2001 average in each year 2004-2016, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	104.3	104.3	104.3	104.3	0.00
2005	98.7	98.8	98.8	98.9	0.05
2006	91.6	92.0	92.1	92.8	0.39
2007	82.0	84.0	84.3	87.7	1.84
2008	73.4	78.8	79.8	89.1	4.98
2009	69.4	80.4	81.8	97.8	9.20
2010	70.6	86.5	88.2	110.1	12.84
2011	73.9	93.5	95.3	121.6	15.26
2012	77.7	99.0	101.3	128.8	16.69
2013	80.3	103.6	105.4	135.2	17.46
2014	83.9	107.0	108.5	139.4	17.78
2015	86.1	109.7	111.3	142.8	17.86
2016	88.3	111.2	113.1	144.6	17.86

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.22	0.22	0.22	0.22	0.000
2005	0.22	0.22	0.22	0.22	0.000
2006	0.22	0.22	0.22	0.22	0.000
2007	0.22	0.22	0.22	0.22	0.000
2008	0.22	0.22	0.22	0.22	0.000
2009	0.22	0.22	0.22	0.22	0.000
2010	0.22	0.22	0.22	0.22	0.000
2011	0.22	0.22	0.22	0.22	0.000
2012	0.22	0.22	0.22	0.22	0.000
2013	0.22	0.22	0.22	0.22	0.000
2014	0.22	0.22	0.22	0.22	0.000
2015	0.22	0.22	0.22	0.22	0.000
2016	0.22	0.22	0.22	0.22	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	48.0	48.0	48.0	48.0	0.00
2005	46.4	46.4	46.4	46.4	0.01
2006	41.5	41.7	41.8	42.1	0.19
2007	34.9	36.2	36.4	38.8	1.27
2008	31.1	35.6	36.3	44.3	4.14
2009	31.6	40.2	41.2	53.3	7.09
2010	34.5	45.5	46.6	62.4	8.85
2011	37.2	49.6	50.7	67.2	9.68
2012	39.3	52.0	53.3	70.5	10.07
2013	40.0	53.9	54.9	72.5	10.21
2014	41.4	54.7	55.8	73.8	10.18
2015	42.2	55.1	56.4	73.5	10.15
2016	42.7	55.3	56.8	74.5	10.14

Table 2.32–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = 0$ in each year 2004-2016, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	106.9	106.9	106.9	106.9	0.00
2005	116.4	116.5	116.5	116.6	0.05
2006	123.2	123.6	123.6	124.4	0.39
2007	124.9	126.9	127.2	130.6	1.86
2008	122.9	128.6	129.6	139.3	5.21
2009	121.8	134.1	135.7	154.2	10.38
2010	124.7	144.7	146.8	173.8	16.00
2011	130.6	156.8	159.8	196.5	20.87
2012	138.7	169.3	172.5	214.1	24.56
2013	143.8	178.9	182.4	228.2	27.13
2014	151.0	188.7	191.5	240.3	28.74
2015	159.6	197.7	200.6	251.8	29.85
2016	164.1	204.6	207.1	261.5	30.32

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.00	0.00	0.00	0.00	0.000
2005	0.00	0.00	0.00	0.00	0.000
2006	0.00	0.00	0.00	0.00	0.000
2007	0.00	0.00	0.00	0.00	0.000
2008	0.00	0.00	0.00	0.00	0.000
2009	0.00	0.00	0.00	0.00	0.000
2010	0.00	0.00	0.00	0.00	0.000
2011	0.00	0.00	0.00	0.00	0.000
2012	0.00	0.00	0.00	0.00	0.000
2013	0.00	0.00	0.00	0.00	0.000
2014	0.00	0.00	0.00	0.00	0.000
2015	0.00	0.00	0.00	0.00	0.000
2016	0.00	0.00	0.00	0.00	0.000

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.0	0.0	0.0	0.0	0.00
2005	0.0	0.0	0.0	0.0	0.00
2006	0.0	0.0	0.0	0.0	0.00
2007	0.0	0.0	0.0	0.0	0.00
2008	0.0	0.0	0.0	0.0	0.00
2009	0.0	0.0	0.0	0.0	0.00
2010	0.0	0.0	0.0	0.0	0.00
2011	0.0	0.0	0.0	0.0	0.00
2012	0.0	0.0	0.0	0.0	0.00
2013	0.0	0.0	0.0	0.0	0.00
2014	0.0	0.0	0.0	0.0	0.00
2015	0.0	0.0	0.0	0.0	0.00
2016	0.0	0.0	0.0	0.0	0.00

Table 2.33–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = F_{OFL}$ in each year 2004-2016, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	102.1	102.1	102.1	102.1	0.00
2005	86.3	86.4	86.4	86.5	0.05
2006	73.2	73.6	73.7	74.3	0.36
2007	63.0	64.8	65.1	68.2	1.69
2008	57.0	62.0	62.7	70.9	4.41
2009	56.6	66.0	66.9	79.8	7.59
2010	60.1	72.3	73.4	89.7	9.47
2011	64.1	77.5	78.3	94.8	10.11
2012	66.6	79.9	81.0	98.3	10.33
2013	67.5	81.1	82.0	100.5	10.47
2014	68.6	81.0	82.4	101.7	10.51
2015	69.2	81.2	82.9	101.5	10.52
2016	69.3	81.2	83.1	101.8	10.60

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.41	0.41	0.41	0.41	0.000
2005	0.39	0.39	0.39	0.39	0.000
2006	0.33	0.33	0.33	0.34	0.002
2007	0.28	0.29	0.29	0.31	0.008
2008	0.25	0.28	0.28	0.32	0.021
2009	0.25	0.30	0.30	0.36	0.035
2010	0.27	0.33	0.33	0.41	0.040
2011	0.29	0.35	0.35	0.41	0.039
2012	0.30	0.36	0.36	0.41	0.036
2013	0.30	0.37	0.36	0.41	0.034
2014	0.31	0.37	0.36	0.41	0.033
2015	0.31	0.37	0.37	0.41	0.032
2016	0.31	0.37	0.37	0.41	0.032

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	83.7	83.7	83.7	83.7	0.00
2005	70.9	70.9	71.0	71.1	0.06
2006	50.0	50.5	50.6	51.6	0.51
2007	35.2	37.8	38.4	43.4	2.63
2008	29.4	37.2	38.9	54.1	8.03
2009	31.4	46.9	49.6	75.0	14.57
2010	37.8	59.0	61.8	95.7	17.76
2011	43.3	67.5	69.5	100.0	18.31
2012	47.3	70.8	73.0	104.9	18.15
2013	47.9	72.4	73.9	103.8	17.93
2014	48.9	72.4	74.1	103.8	17.66
2015	49.3	72.3	74.4	104.7	17.62
2016	49.5	71.7	74.5	105.3	17.70

Table 2.34–Equilibrium reference points and projections for GOA Pacific cod spawning biomass (1000s of t), fishing mortality, and catch (1000s of t) under the assumption that $F = max\ F_{ABC}$ in each year 2004-2005 and $F = F_{OFL}$ thereafter, where future recruitment is drawn from a distribution based on estimated recruitments spawned during the period 1977-2002. See Table 2.27 for symbol definitions.

Equilibrium Reference Points

SPR	Spawning Biomass	Fishing Mortality	Catch
100%	222.0	0.00	0.0
40%	88.9	0.34	71.6
35%	77.8	0.41	77.2

Spawning Biomass Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	102.9	102.9	102.9	102.9	0.00
2005	90.5	90.6	90.6	90.7	0.05
2006	78.3	78.7	78.8	79.5	0.37
2007	65.7	67.5	67.8	71.0	1.68
2008	58.4	63.4	64.1	72.2	4.39
2009	57.2	66.6	67.5	80.4	7.55
2010	60.4	72.5	73.6	89.9	9.43
2011	64.2	77.6	78.4	94.8	10.10
2012	66.6	79.9	81.0	98.3	10.33
2013	67.4	81.1	81.9	100.4	10.47
2014	68.6	80.9	82.4	101.7	10.51
2015	69.2	81.2	82.9	101.4	10.52
2016	69.3	81.2	83.1	101.8	10.60

Fishing Mortality Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	0.34	0.34	0.34	0.34	0.000
2005	0.34	0.34	0.34	0.34	0.000
2006	0.35	0.36	0.36	0.36	0.002
2007	0.29	0.30	0.30	0.32	0.008
2008	0.26	0.28	0.29	0.33	0.021
2009	0.25	0.30	0.30	0.36	0.035
2010	0.27	0.33	0.33	0.41	0.040
2011	0.29	0.35	0.35	0.41	0.039
2012	0.30	0.36	0.36	0.41	0.036
2013	0.30	0.37	0.36	0.41	0.035
2014	0.31	0.37	0.36	0.41	0.033
2015	0.31	0.37	0.37	0.41	0.032
2016	0.31	0.37	0.37	0.41	0.032

Catch Projections

Year	L90%CI	Median	Mean	U90%CI	St. Dev.
2004	71.2	71.2	71.2	71.2	0.00
2005	64.4	64.4	64.4	64.4	0.02
2006	56.6	57.2	57.3	58.3	0.56
2007	37.9	40.6	41.2	46.3	2.73
2008	30.5	38.4	40.2	55.5	8.13
2009	31.9	47.4	50.1	75.6	14.55
2010	37.9	59.1	61.8	95.5	17.70
2011	43.3	67.4	69.5	99.8	18.28
2012	47.2	70.7	72.9	104.8	18.15
2013	47.8	72.4	73.8	103.8	17.94
2014	48.9	72.4	74.1	103.8	17.66
2015	49.3	72.3	74.4	104.7	17.62
2016	49.5	71.7	74.5	105.3	17.71

Table 2.35a–Bycatch of nontarget and “other” species taken in the GOA Pacific cod trawl fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the GOA Pacific cod trawl fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod trawl fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	201	109	127	124	69	75	0.22	0.20	0.23	0.13	0.12	0.08
skates	476	411	385	219	272	120	0.15	0.09	0.19	0.07	0.15	0.02
shark	11	7	4	1	1	0	0.09	0.00	0.12	0.02	0.01	0.00
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
dogfish	30	624	14	21	61	3	0.05	0.72	0.04	0.05	0.12	0.02
sleepershk	17	6	5	11	0	26	0.12	0.07	0.01	0.02	0.00	0.12
octopus	25	1	4	0	3	7	0.11	0.01	0.03	0.00	0.03	0.02
squid	1	1	1	0	1	0	0.01	0.01	0.03	0.01	0.01	0.00
smelts	0	1	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0		0		0.00	0.00	0.00		1.00	
sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.56
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
sandlance	0	0	0	0	0	0	0.00	1.00	1.00	0.97	0.12	1.00
grenadier	0	1	17	114	376	0	0.00	0.00	0.00	0.01	0.04	0.00
otherfish	58	211	110	43	68	42	0.10	0.03	0.13	0.04	0.10	0.02
crabs	1	12	1	0	0	0	0.08	0.47	0.06	0.03	0.06	0.04
starfish	63	59	62	22	27	22	0.06	0.05	0.04	0.02	0.06	0.04
jellyfish	7	5	1	1	13	1	0.18	0.03	0.01	0.02	0.05	0.00
invertunid	2	28	0	5	1	0	0.22	0.65	0.10	0.31	0.13	0.00
seapen/whip	0	0	3	0	0	0	0.00	0.01	0.99	0.00	0.00	0.00
sponge	0	1	1	1	1	0	0.04	0.24	0.10	0.12	0.26	0.09
anemone	3	3	11	1	3	6	0.17	0.20	0.65	0.07	0.21	0.27
tunicate	1	0	0	0	0	0	0.43	0.13	0.38	0.05	0.04	0.03
benthinv	3	22	11	1	1	0	0.11	0.72	0.42	0.07	0.06	0.09
snails	0	0	0	0	0	0						
echinoderm	3	23	2	2	1	2	0.13	0.72	0.24	0.31	0.12	0.26
coral	0	0	0	0	0	0	0.00	0.01	0.01	0.01	0.00	0.01
shrimp	0	0	0	0	0	0	0.00	0.08	0.02	0.01	0.03	0.01
birds	0	0	0	0	0	0	0.00	0.07	0.00	0.00	0.00	0.00

Table 2.35b–Bycatch of nontarget and "other" species taken in the GOA Pacific cod longline fishery. The first part of the table ("Bycatch in...") shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the GOA Pacific cod longline fishery, broken down by year. The second part of the table ("Proportion of...") shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod longline fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	63	181	207	203	197	291	0.07	0.33	0.38	0.22	0.33	0.31
skates	478	461	789	1823	617	5005	0.15	0.10	0.39	0.56	0.34	0.77
shark	2	4	8	2	1	5	0.02	0.00	0.25	0.03	0.01	0.19
salmonshk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
dogfish	28	104	146	8	111	7	0.04	0.12	0.47	0.02	0.23	0.06
sleepershk	42	14	501	366	66	40	0.31	0.19	0.90	0.60	0.26	0.18
octopus	1	25	17	16	6	7	0.00	0.22	0.10	0.09	0.07	0.02
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0		0		0.00	0.00	0.00		0.00	
sticheidae	0	0	4	0	0	0	0.00	0.00	1.00	0.00	0.01	0.00
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
sandlance	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
grenadier	191	0	423	0	0	92	0.02	0.00	0.04	0.00	0.00	0.01
otherfish	15	50	36	39	2	128	0.03	0.01	0.04	0.04	0.00	0.06
crabs	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
starfish	304	162	765	199	347	207	0.31	0.13	0.51	0.22	0.74	0.40
jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	0	0	0	5	0	4	0.05	0.00	0.17	0.34	0.05	0.32
seapen/whip	0	3	0	1	0	0	0.00	0.99	0.00	0.87	0.00	0.07
sponge	0	0	0	0	0	0	0.00	0.00	0.01	0.01	0.01	0.01
anemone	0	8	5	5	0	1	0.02	0.52	0.27	0.33	0.02	0.06
tunicate	0	0	0	1	0	0	0.00	0.00	0.00	0.17	0.00	0.00
benthinv	0	1	1	1	5	0	0.00	0.03	0.03	0.07	0.40	0.07
snails	0	0	0	0	0	0						
echinoderm	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.04
coral	0	0	0	0	0	0	0.00	0.00	0.05	0.00	0.00	0.02
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	0	1	1	1	1	0	0.13	0.12	0.16	0.21	0.43	0.40

Table 2.35c–Bycatch of nontarget and “other” species taken in the GOA Pacific cod pot fishery. The first part of the table (“Bycatch in...”) shows the amount (metric tons or individuals, as appropriate) of each species group taken as bycatch in the GOA Pacific cod pot fishery, broken down by year. The second part of the table (“Proportion of...”) shows the same quantity expressed relative to the total GOA catch (taken in all target categories with all gears) of that species group in that year. An empty cell in the second part of the table indicates that no catch of that group was observed in the GOA during that year.

	Bycatch in GOA Pacific cod pot fishery						Proportion of total GOA catch					
Species group	1997	1998	1999	2000	2001	2002	1997	1998	1999	2000	2001	2002
sculpin	106	61	106	357	29	79	0.12	0.11	0.19	0.38	0.05	0.09
skates	1	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shark	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
salmonshk	0	0	1	0	0	0	0.00	0.00	0.01	0.00	0.00	0.00
dogfish	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
sleepershk	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
octopus	168	74	142	137	63	252	0.72	0.66	0.85	0.78	0.71	0.84
squid	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
smelts	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
gunnel	0	0	0		0		0.00	0.00	0.00		0.00	
sticheidae	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sandfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
lanternfish	0	0	0		0	0	0.00		0.00		0.00	0.00
sandlance	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
grenadier	0	0	0	0	1	0	0.00	0.00	0.00	0.00	0.00	0.00
otherfish	30	4	92	19	52	43	0.05	0.00	0.11	0.02	0.07	0.02
crabs	6	10	9	10	2	1	0.41	0.42	0.81	0.84	0.36	0.19
starfish	468	210	633	566	35	66	0.47	0.17	0.42	0.63	0.08	0.13
jellyfish	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
invertunid	0	0	0	0	0	0	0.00	0.00	0.00	0.01	0.01	0.03
seapen/whip	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
sponge	0	0	5	0	0	0	0.03	0.00	0.39	0.04	0.01	0.01
anemone	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
tunicate	0	0	0	0	0	0	0.00	0.03	0.41	0.02	0.00	0.00
benthinv	10	2	10	4	1	2	0.40	0.08	0.40	0.34	0.08	0.28
snails	0	0	0	0	0	0						
echinoderm	1	0	1	1	1	1	0.06	0.00	0.09	0.14	0.16	0.09
coral	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
shrimp	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
birds	0	0	0	0	0	0	0.00	0.00	0.01	0.00	0.02	106

Table 2.36--Summary of major results for the stock assessment of Pacific cod in the GOA region.

Tier	3a
Reference mortality rates	
M	0.37
$F_{40\%}$	0.34
$F_{35\%}$	0.41
Equilibrium spawning biomass	
$B_{35\%}$	77,800 t
$B_{40\%}$	88,900 t
$B_{100\%}$	222,000 t
Projected biomass for 2004	
Spawning (at *max* F_{ABC})	103,000 t
Age 3+	484,000 t
ABC for 2004	
F_{ABC} (maximum permissible)	0.34
F_{ABC} (recommended)	0.29
ABC (maximum permissible)	71,200 t
ABC (recommended)	62,800 t
Overfishing level for 2004	
Fishing Mortality	0.41
Catch	83,700 t

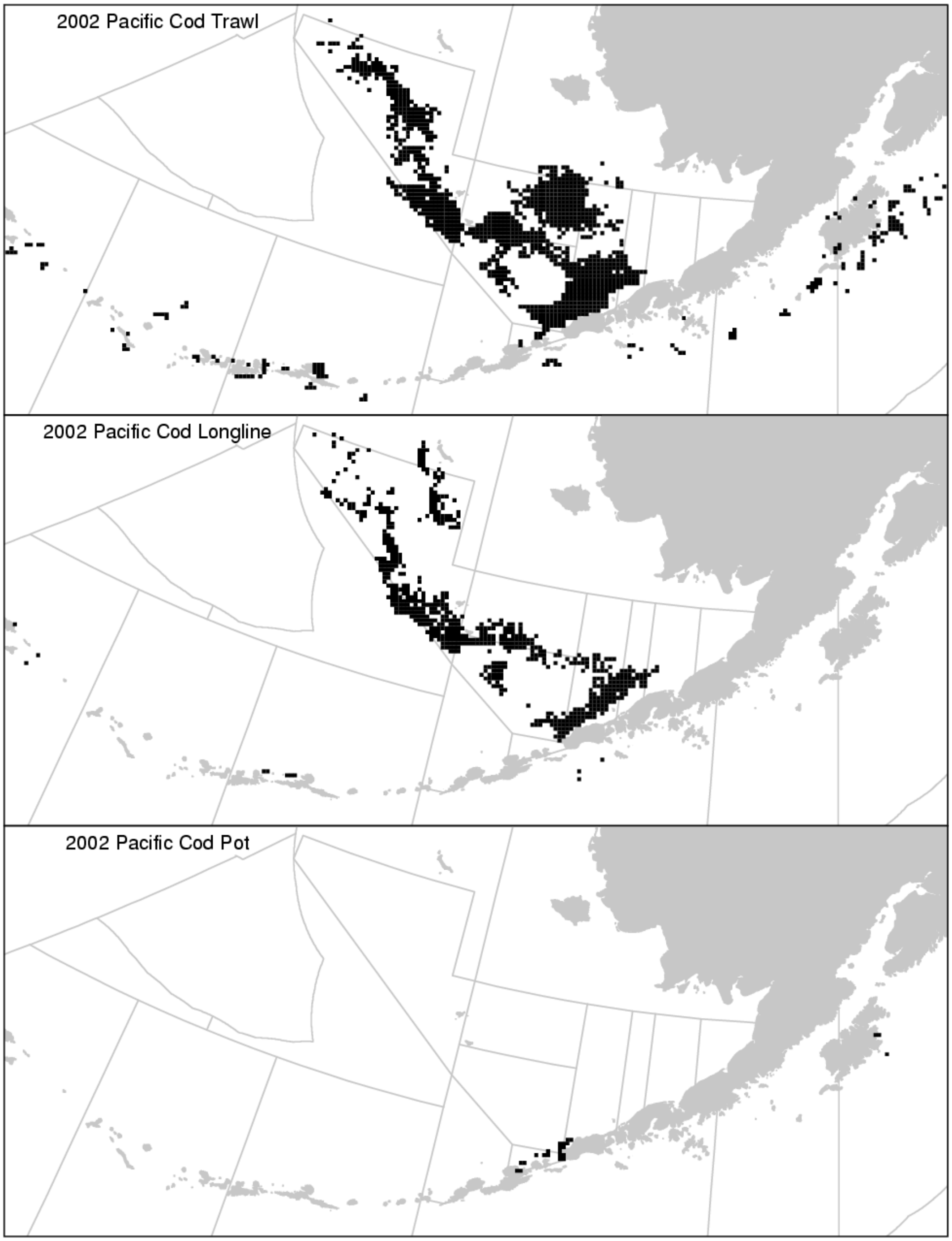
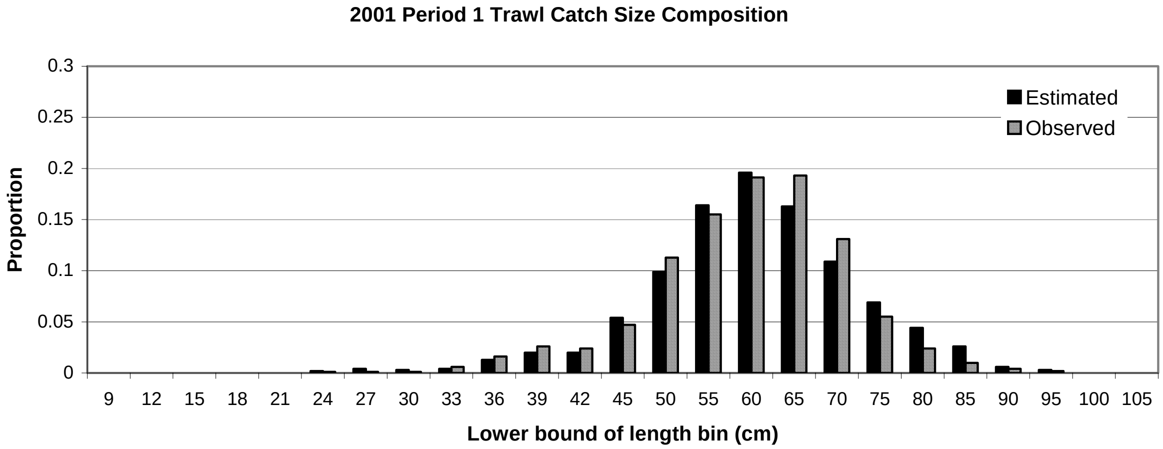
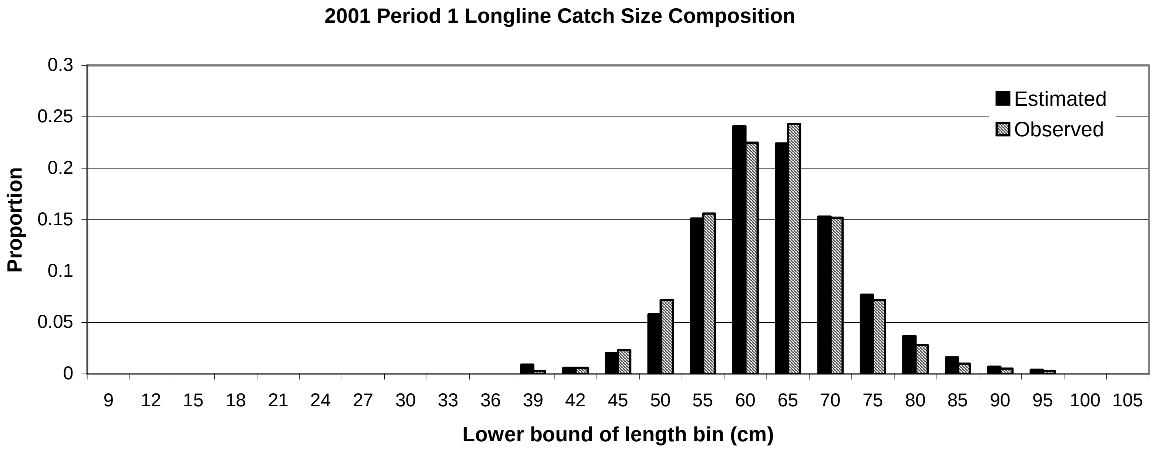


Figure 2.1.
Maps showing each 10 km × 10 km square with at least 3 observed hauls/sets containing Pacific cod in 2002, by gear type.





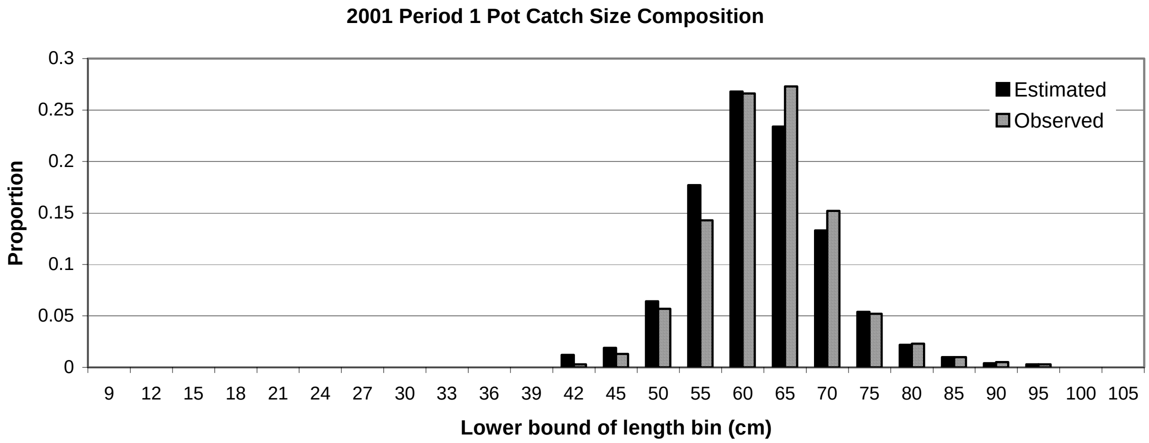
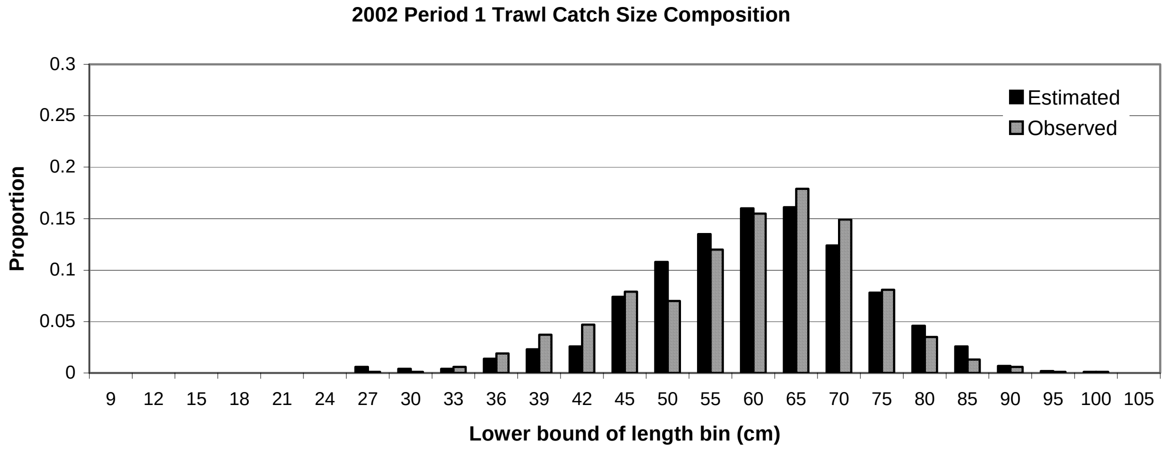
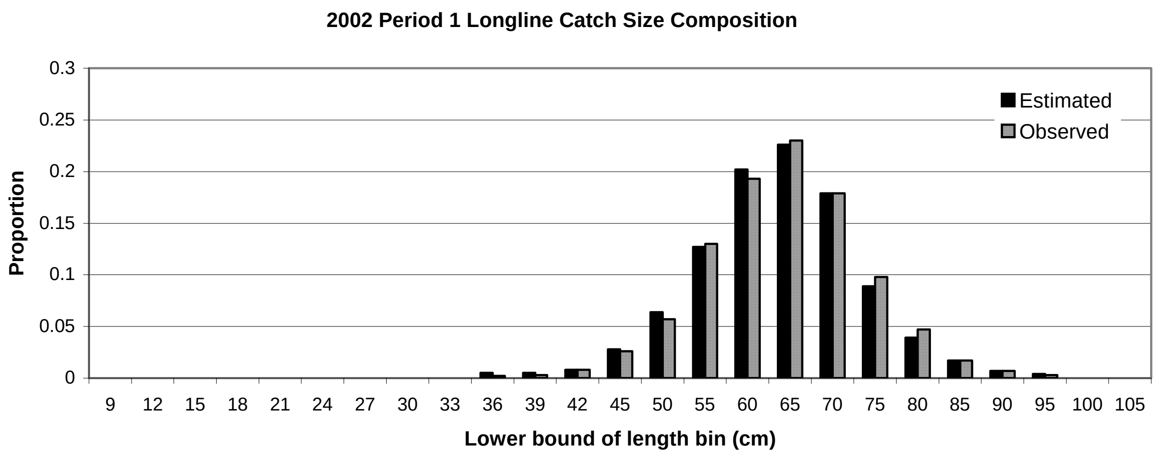


Figure 2.2–Estimated and observed size compositions from the 2001 period 1 fisheries.





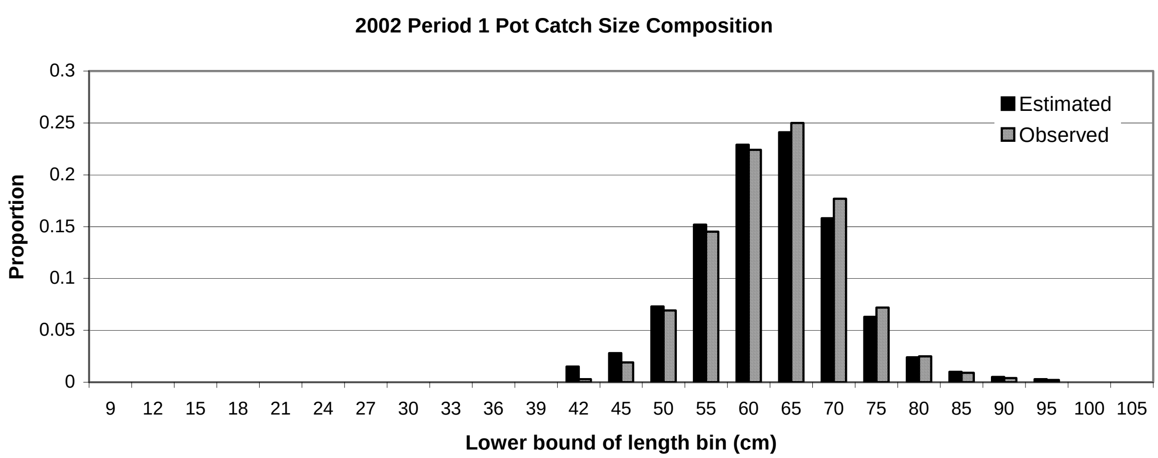


Figure 2.3–Estimated and observed size compositions from the 2002 period 1 fisheries.

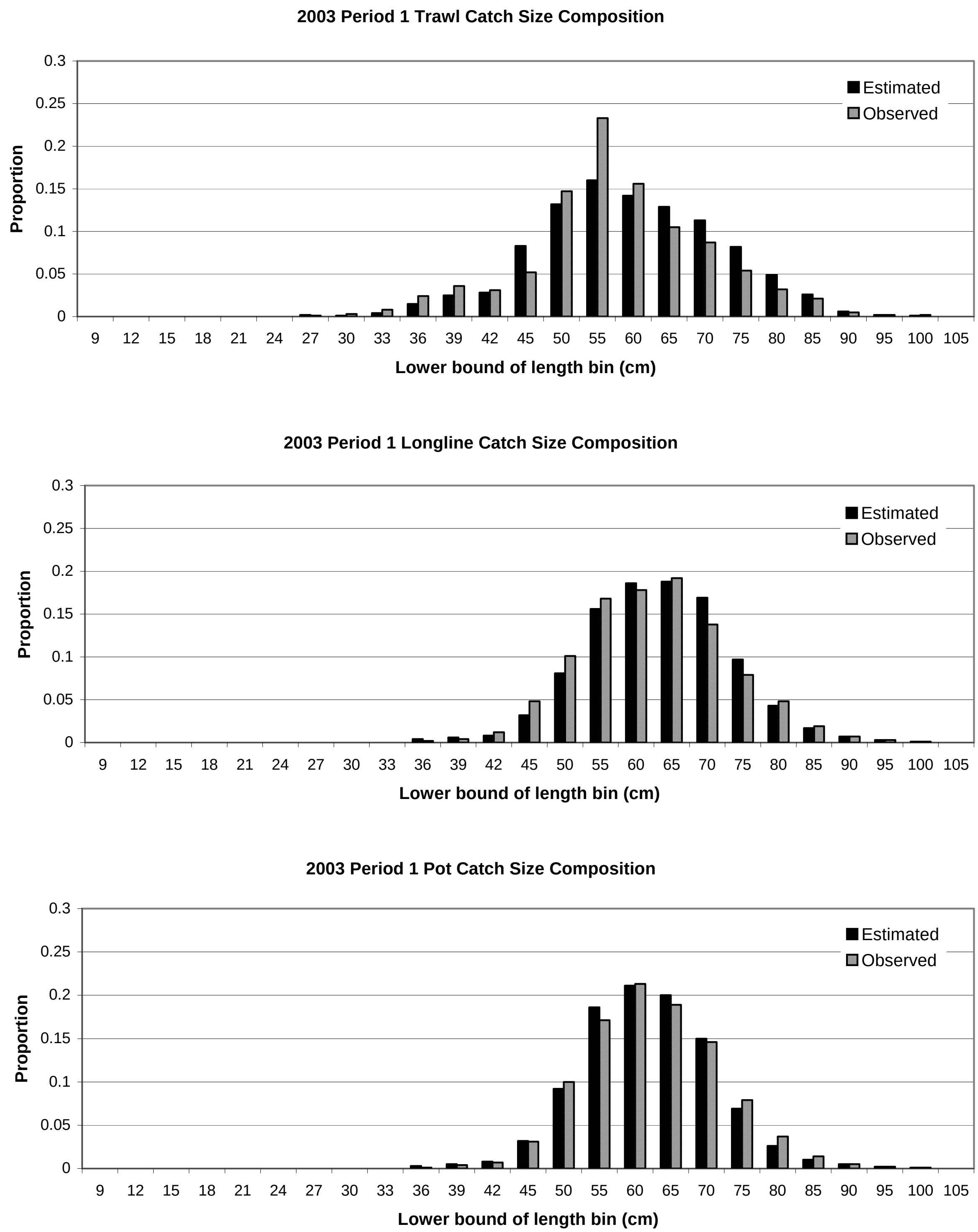
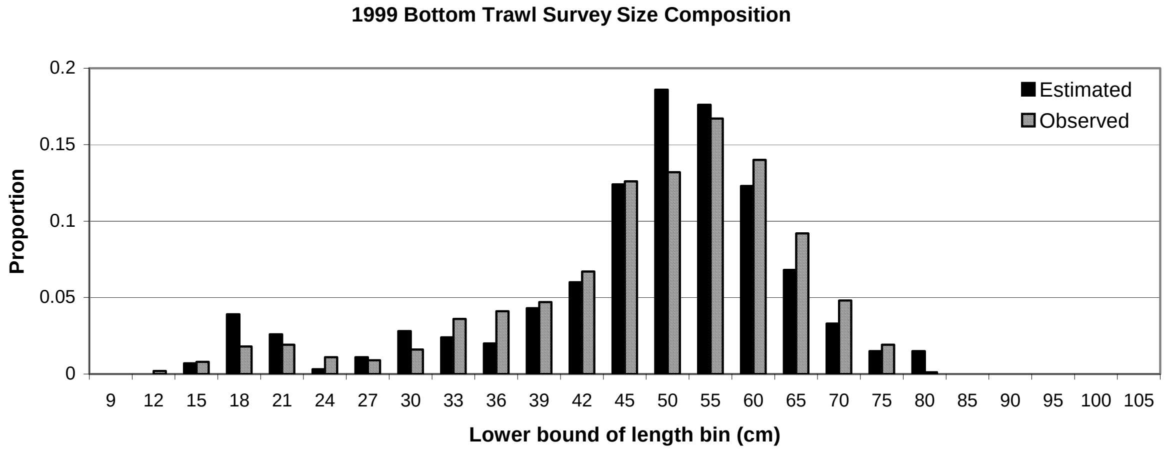
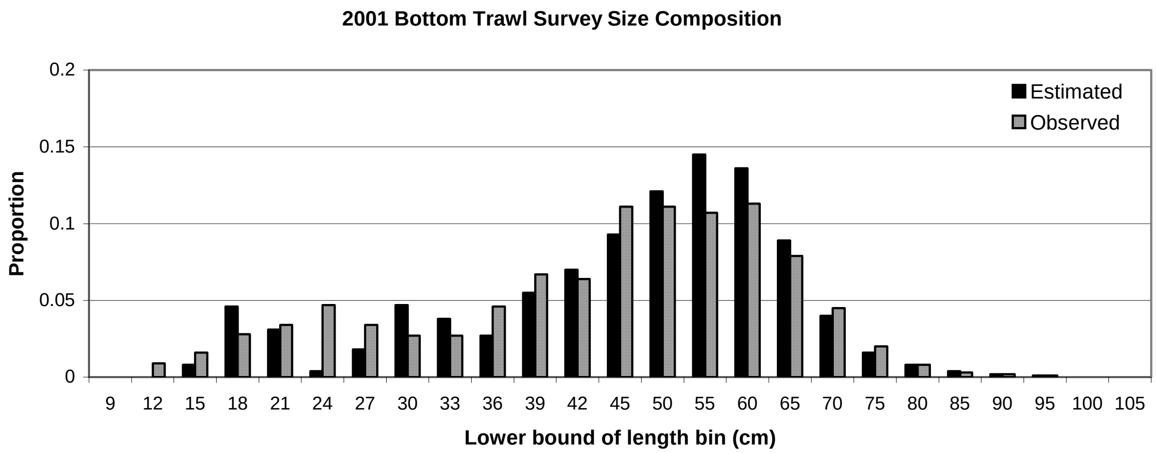


Figure 2.4–Estimated and observed size compositions from the 2003 period 1 fisheries.





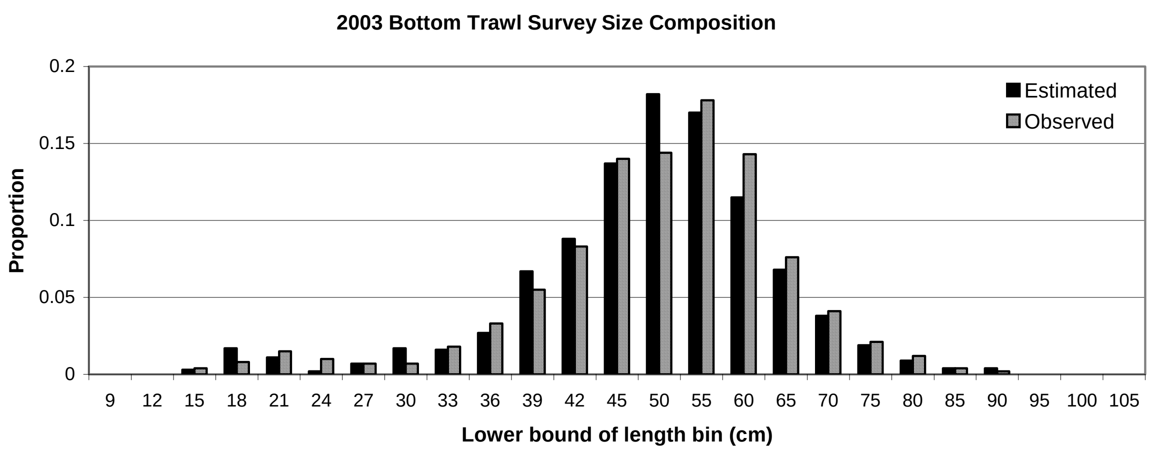


Figure 2.5–Estimated and observed size compositions from the 3 most recent surveys.

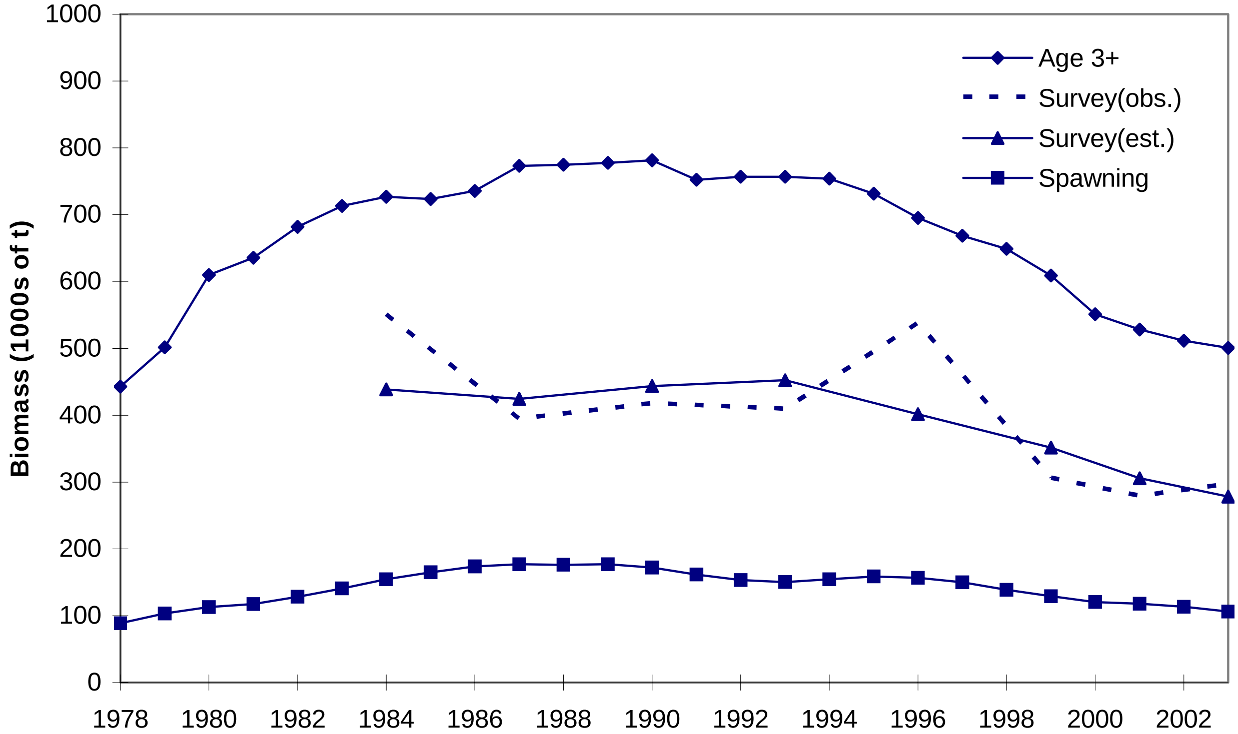


Figure 2.6–Time series of biomass estimates.

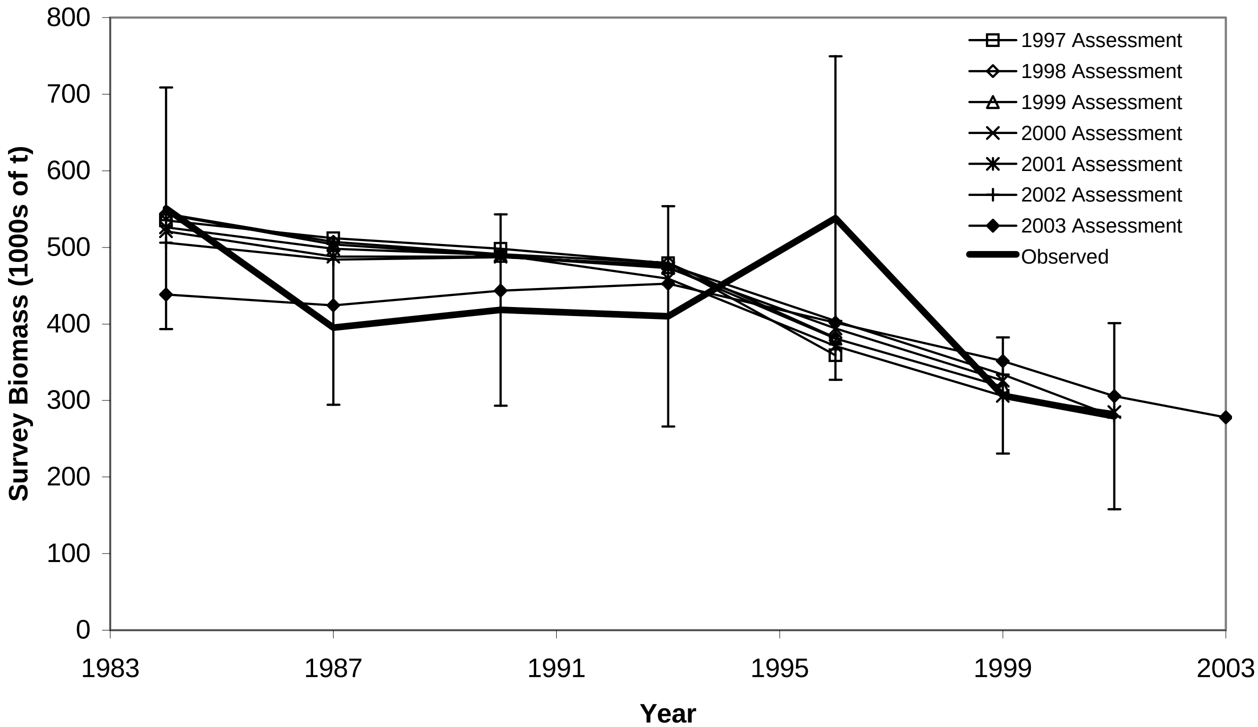


Figure 2.7–Retrospective analysis of estimated survey biomass, 1997-present. The vertical error bars around the observed survey biomass represent 1.96 standard deviations on either side of the mean.

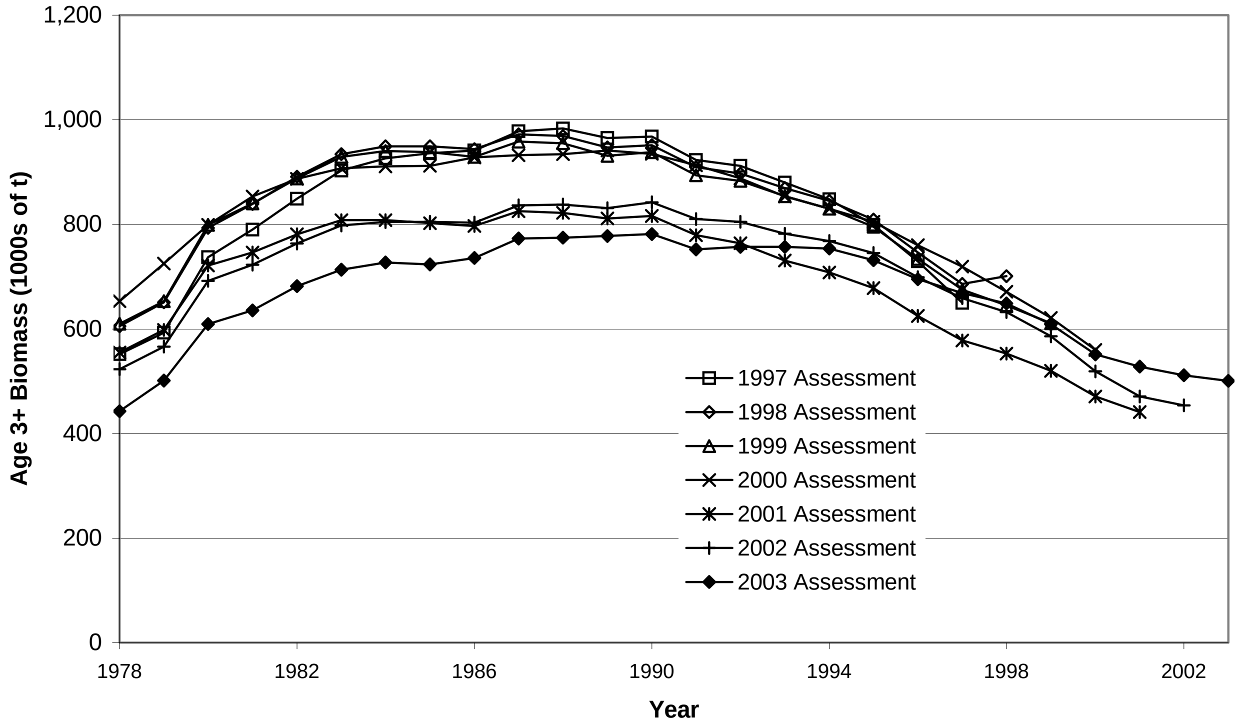


Figure 2.8–Retrospective analysis of estimated age 3+ biomass, 1997-present.

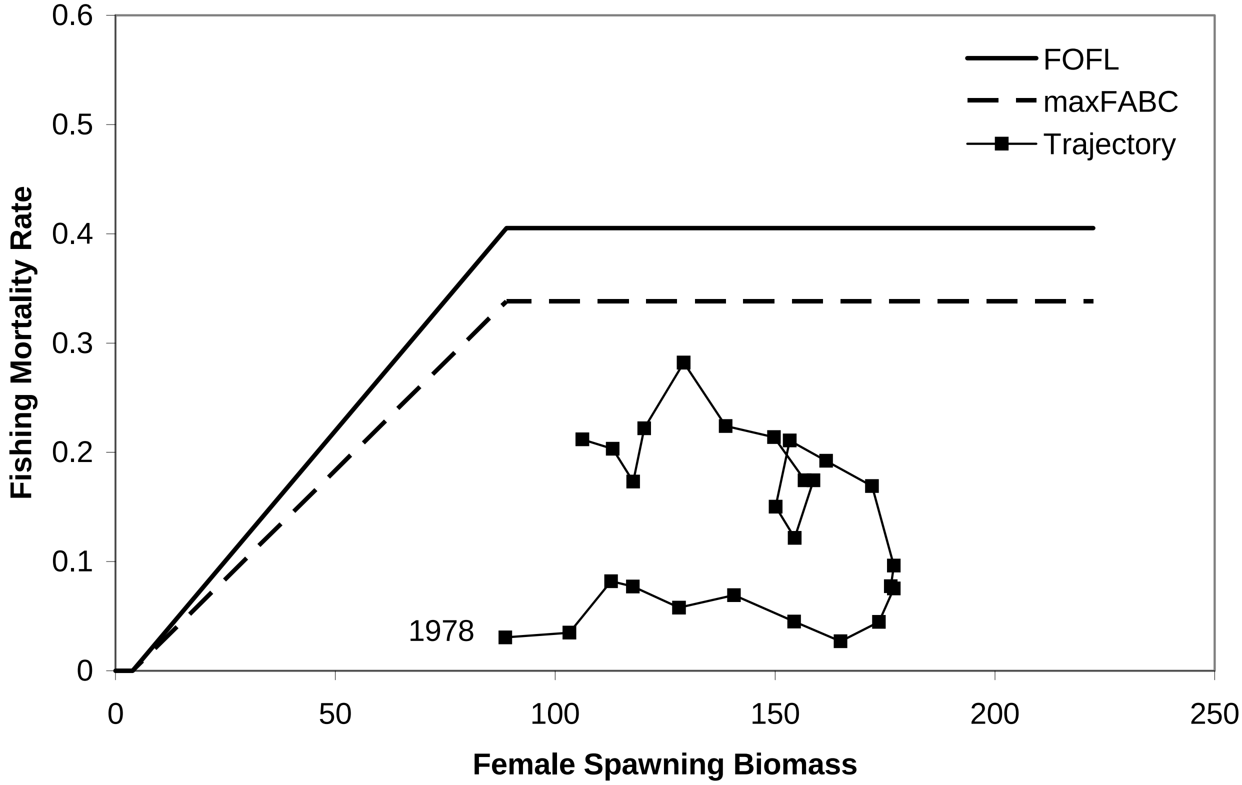


Figure 2.9–Trajectory of fishing mortality and female spawning biomass, 1978-present.

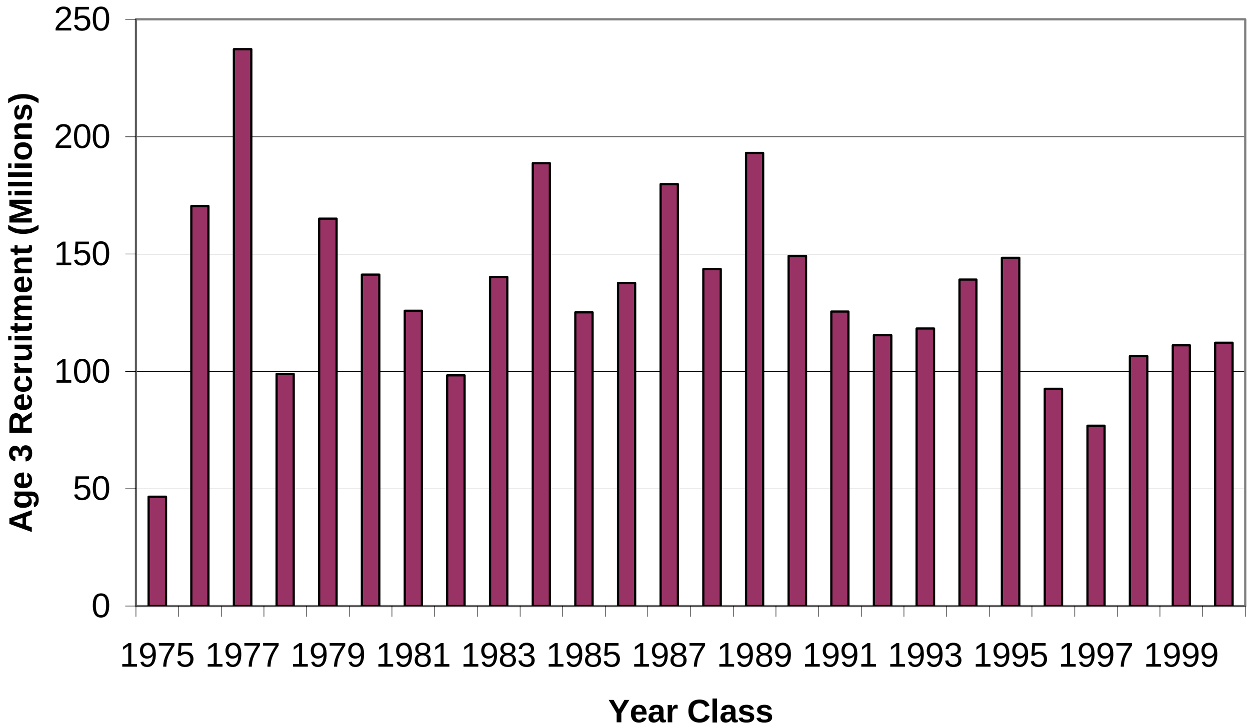


Figure 2.10–Pacific cod recruitment at age 3 as estimated by the assessment model.

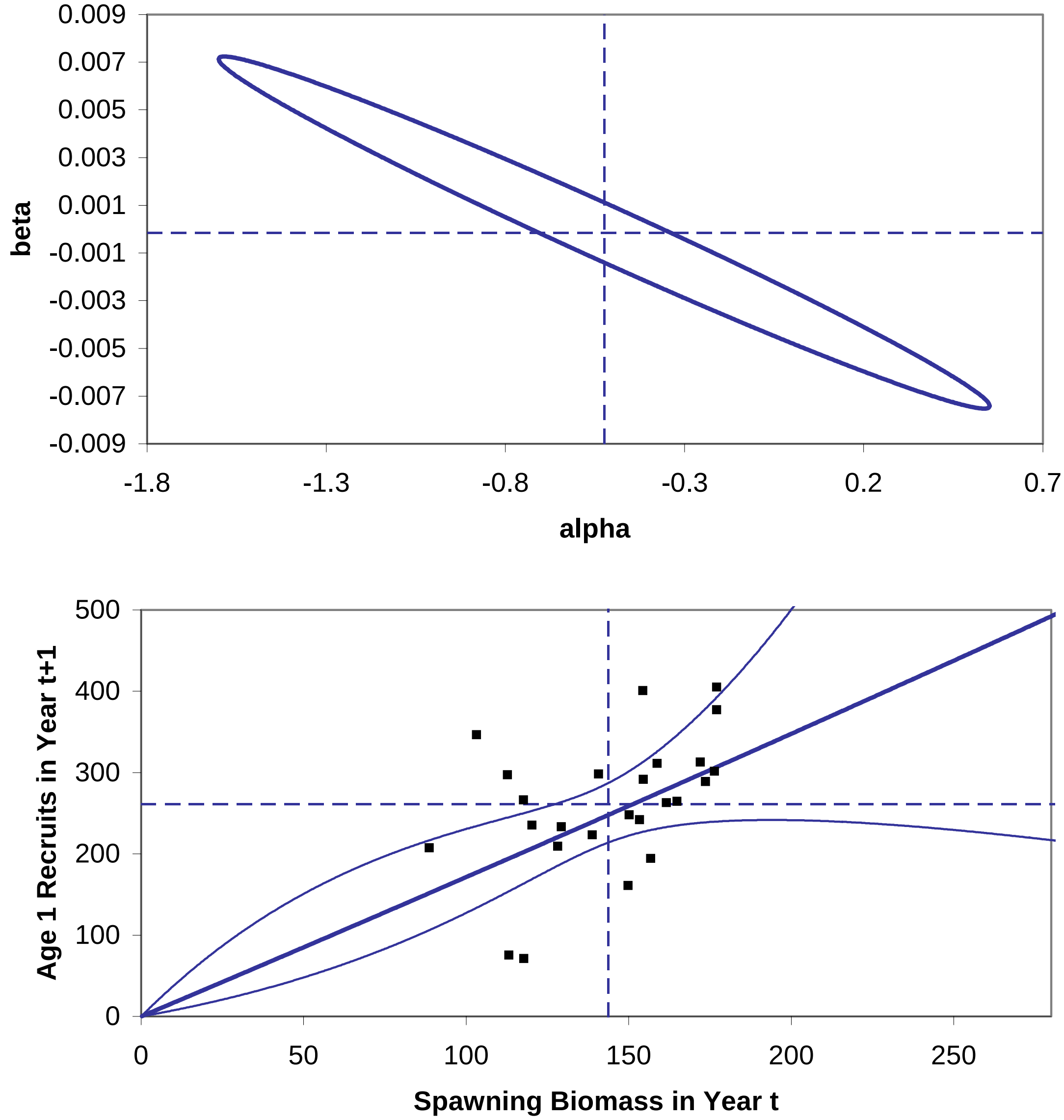


Figure 2.11–Some aspects of uncertainty surrounding the stock-recruitment relationship. The upper panel shows a 95% confidence ellipse for the estimated parameters of the stock-recruitment relationship, with dashed lines indicating the location of the point estimates. The lower panel shows the data (small squares), the estimated relationship (bold curve), and the 95% confidence interval around the curve (thin curves), with dashed lines indicating the locations of the data means. See text for details and caveats.

Appendix 2A: Recent changes in patterns of fishing for Pacific cod

1. Introduction

At its April 2003 meeting, the Council requested that the following questions be addressed in this year's SAFE reports:

1) Has the pattern of fishing for Pacific cod in the BSAI changed in recent years with respect to catch location, concentrations, timing, amount of catch by area, and number and type of vessels?
2) What seems to be driving these changes (environmental conditions, economics of fishing, location of facilities, etc.)?
3) Do these changes have conservation impacts for Pacific cod, other species like rockfish, or habitats?
4) Do these changes and conservation issues have management implications for TAC setting, seasons, gear, or allocations?

Following the meeting, Council staff requested that similar consideration be given to GOA Pacific cod.

2. Methods

The "blend" database was used to address the Council's questions. This database is limited to some extent by the fact that it cannot address questions relating to the number of vessels, but it can address questions relating to the number of processors, which can be shore plants, motherships, or catcher/processors. The blend database is also limited to some extent by the fact that it does not include catches from the State-managed fishery for Pacific cod.

The Council did not define what it meant by the term "recent years." The years 1998-2002 were chosen as a reasonable interpretation (complete 2003 data were not available at the time of this analysis).

Data were obtained by querying the blend database for number of processors and amount of catch taken in each combination of three-digit statistical area, gear, and month for the years 1998-2002. This resulted in a total of 2,159 records, with an average (across years) total catch of 240,761 t. Two problems arose with these data. First, most of the records were associated with very small catches. For example, 57% of the records were associated with catches less than 100 t apiece, while the remaining 43% of the records accounted for 98% of the total catch. Second, 36% of the records were associated with fewer than three processors. Confidentiality restrictions preclude displaying such records directly or in a way that would permit them to be reconstructed by a reader. With some data sets, it might be possible to deal with this problem simply by eliminating all records associated with fewer than three processors. Because the present exercise evaluates whole time series of individual records, however, deletion of individual records in this manner can cause other problems. Instead, the data were purged of all records pertaining to any area-gear-month category for which the number of processors was less than three in *any* of the years 1998-2002. This left 740 records which accounted for 186,271 t (77%) of the average total catch.

In their raw form, the data describe the number of processors and amount of catch in each year for a series of area-gear-month categories. The data describing processor numbers cannot be aggregated beyond this point, because the same processor can participate in more than one area, gear, or month, meaning that summing the data across factors would tend to overestimate the number of processors. The catch data, on the other hand, *can* be aggregated, because each fish can be caught only once. The catch data were therefore aggregated at various levels to guard against the possibility of significant trends being masked by an inappropriate choice of resolution. The raw data describe a three-factors-at-a-time resolution, which is the highest resolution possible with these data. The next lower level of resolution is achieved by aggregating across one of the factors (area, gear, or month) to achieve a two-factors-at-a-time resolution (area-and-gear, area-and-month, or month-and-gear). The lowest level of resolution is achieved by aggregating across two of the factors (gear and month, area and month, or area and gear) to achieve a one-factor-at-a-time resolution (area, gear, or month).

The data in each aggregation and category were tested for the presence of statistically significant trends in three ways. First, a linear relationship was regressed through each time series and the slope was tested to determine whether it was significantly different from zero. Second, each time series was split into two portions, the first consisting of the years 1998-1999 and the second consisting of the years 2000-2002, then the difference between the means of the two portions was computed, and finally this difference was tested to determine whether it was significantly different from zero. The third test was the same as the second, except that the partitions consisted of the years 1998-2000 and 2001-2002. For all three tests, a 5% significance level was used.

It should be noted that conventional measures of statistical significance can be misleading in analyses of this type. Ideally, a test of significance should be applied to a single hypothesis. Use of a 5% significance level means that there is no more than a 5% chance of accepting a particular hypothesis if that hypothesis is actually false. Here, on the other hand, *many* hypotheses are being tested. If all the hypotheses are false, use of a 5% significance level means that one would expect to accept 5% of them anyway. Therefore, "significant" here should be interpreted heuristically rather than statistically. To emphasize this caveat, "significant" will be used hereafter with quotation marks.

3. Results

The results are described in order of resolution, proceeding from lowest to highest. In this section, the term "data" refers to the set of records remaining after all confidentiality-precluded records were eliminated, and the term "average total catch" refers to the average total catch associated with the remaining records (186,271 t).

3.1. One Factor at a Time

3.1.1. Area

A total of 16 reporting areas (ten in the BSAI and six in the GOA) were represented in the data. Eight (50%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.1a). These eight areas represent 44% of the average total catch. The catch trends in all eight of these areas were negative.

3.1.2. Gear

A total of three gears (longline, pot, and trawl) were represented in the data. Only one of these (pot) was also associated with "significant" results for at least one of the three tests (Table 2A.1b). This gear represents 4% of the average total catch. The catch trend for this gear was negative.

3.1.3. Month

A total of 12 months were represented in the data. Five (42%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.1c). These five months represent 52% of the average total catch. The catch trends in three (60%) of these months were negative.

3.2. Two Factors at a Time

3.2.1. Area and Gear

A total of 28 area-and-gear categories were represented in the data. Nine (32%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.2a). These nine categories represent 25% of the average total catch. The catch trends in eight (89%) of these categories were negative.

3.2.2. Area and Month

A total of 108 area-and-month categories were represented in the data. Twenty-five (23%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.2b). These 25 categories represent 21% of the average total catch. The catch trends in 19 (76%) of these categories were negative.

3.2.3. Gear and Month

A total of 26 gear-and-month categories were represented in the data. Seven (27%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.2c). These seven categories represent 23% of the average total catch. The catch trends in five (71%) of these categories were negative.

3.3. Three Factors at a Time

3.3.1. Catch

A total of 148 area-gear-month categories were represented in the data. Thirty (20%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.3a). These 30 categories represent 20% of the average total catch. The catch trends in 25 (83%) of these categories were negative.

3.3.2. Number of Unique Processors

A total of 148 area-gear-month categories were represented in the data. Twenty-eight (19%) of these were also associated with "significant" results for at least one of the three tests (Table 2A.3b). The processor trends in 19 (68%) of these categories were negative.

4. Discussion

The Council's request was framed as a set of four questions, addressed in order below. (Note: The following responses consider both the BSAI and GOA fisheries.)

4.1. Has the pattern of fishing for Pacific cod in the BSAI changed in recent years with respect to catch location, concentrations, timing, amount of catch by area, and number and type of vessels?

For most categories, the available data do not demonstrate "significant" changes in fishing patterns for Pacific cod with respect to area, gear, or month. Of those categories that *do* show "significant" changes, the trend is most often negative. The preceding statements are true regardless of whether trends are measured in terms of catch or number of processors. In terms of catch (Tables 2A.1-

2A.3a), the proportion of categories showing "significant" positive trends varied from 0% to 17%, with an average of 5%. In terms of processor numbers (Table 2A.3b), only 6% of the categories showed a "significant" positive trend.

A number of caveats should be applied to the above, however. First, the data do not include catches from the State-managed fishery or records which were omitted because of confidentiality considerations. Second, although consideration was given here to three levels of resolution and every possible combination of three factors within these three levels, it is conceivable that "significant" trends might exist with respect to other (presumably finer) levels of resolution or other factors. Third, the fact that a given trend did not qualify as "significant" in this analysis does not mean that the trend does not exist or, if such a trend does exist, that it is unimportant. This is one of the fundamental difficulties involved with attempts to detect "recent" trends: When the time series is short, the trend either has to be very strong or very consistent to qualify as "significant."

4.2. What seems to be driving these changes (environmental conditions, economics of fishing, location of facilities, etc.)?

Just as it is difficult to find "significant" trends on the basis of only a few years of data, it is also difficult (perhaps more so) to find "significant" correlations between these trends and exogenous factors such as environmental conditions. For short time series such as those considered in this analysis, effort is probably better spent toward identifying exogenous factors with known, direct relationships to catches of Pacific cod. One obvious choice is TAC. Given that catch is often limited by TAC, that TACs have been declining recently, and that most of the "significant" catch trends are negative, it is reasonable to conclude that declining TACs have been one of the driving factors in recent catch trends. Identification of other causative factors may be possible in the future.

4.3. Do these changes have conservation impacts for Pacific cod, other species like rockfish, or habitats?

Because is unlikely that negative trends in either catch or processor numbers will adversely impact stocks of Pacific cod, other species, or habitats, it is appropriate that the answer to the above question be focused on those few categories for which "significant" positive trends were demonstrated. The positive catch trends from Tables 2A.1-2A.3a have been consolidated and summarized in Table 2A.4. As noted in Section 4.1, the proportion of categories in Tables 2A.1-2A.3a showing "significant" positive trends in catch varied from 0% to 17%, with an average of 5%. In terms of processor numbers (Table 2A.3b), only 6% of the categories showed a "significant" positive trend. Because relatively few positive trends have been demonstrated, it is unlikely that they would have major conservation impacts unless they were very large. However, as Table 2A.4 shows, the increases within a particular aggregation never sum to more than about 4% of the average total catch. Therefore, based on the evidence presented here, it appears unlikely that recent changes in patterns of fishing for Pacific cod have had major conservation impacts.

4.4. Do these changes and conservation issues have management implications for TAC setting, seasons, gear, or allocations?

The information presented here does not suggest that recent changes in patterns of fishing for Pacific cod have management implications. Because measures such as TAC allocation are determined in part by policy considerations, however, it is possible that some management implications may exist but are outside the scope of this study. Another consideration outside the scope of this study has to do with the relationship between the spatiotemporal distribution of the fisheries and that of the stock. Regardless of whether fishing patterns have *changed*, it may be important to understand how the *patterns themselves* interact with the stock. Research designed to increase the spatiotemporal resolution of the Pacific cod assessments is underway. Once this research has been completed, it may be easier to determine whether changes in overall TAC or TAC allocation are likely to be beneficial.

Table 2A.1a. Three-digit reporting areas in which “significant” catch trends were detected. Key: “slope” = slope of linear fit through the time series of catches, “dif1” = average 2000-2002 catch minus average 1998-1999 catch, “dif2” = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a “significant” result at the 5% level.

	Catch					Measure of Trend		
Area	1998	1999	2000	2001	2002	slope	dif1	dif2
517	40,038	38,512	43,951	21,860	31,599	-3,353	-6,805	**-14,104**
543	121	65	63	43	16	**-23**	-52	-53
610	18,036	19,060	16,769	10,719	10,332	-2,375	-5,941	**-7,430**
620	9,901	6,546	3,999	3,350	4,074	-1,485	**-4,416**	-3,104
630	30,397	31,293	25,122	21,688	18,379	**-3,364**	**-9,115**	**-8,904**
640	10	11	1	6	5	-2	**-7**	-2
650	70	33	24	12	8	**-14**	-36	-32
659	210	142	95	56	20	**-46**	-119	-110

Table 2A.1b. Gear types in which "significant" catch trends were detected. Key: "slope" = slope of linear fit through the time series of catches, "dif1" = average 2000-2002 catch minus average 1998-1999 catch, "dif2" = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a "significant" result at the 5% level.

	Catch					Measure of Trend		
Gear	1998	1999	2000	2001	2002	slope	dif1	dif2
POT	8,258	10,182	10,550	2,931	2,060	-1,965	-4,040	**-7,168**

Table 2A.1c. Months in which“significant” catch trends were detected. Key: “slope” = slope of linear fit through the time series of catches, “dif1” = average 2000-2002 catch minus average 1998-1999 catch, “dif2” = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a “significant” result at the 5% level.

	Catch					Measure of Trend		
Month	1998	1999	2000	2001	2002	slope	dif1	dif2
1	25,480	24,868	26,674	14,345	19,868	-2,175	-4,878	**-8,568**
2	50,124	49,992	52,930	30,824	39,726	-3,996	-8,898	**-15,741**
4	19,162	21,286	19,898	11,750	12,030	-2,380	-5,665	**-8,225**
6	132	132	84	714	1,311	294	571	**896**
9	7,682	9,454	15,207	16,760	14,664	2,127	**6,976**	4,931

Table 2A.2a. Area-and-gear categories in which "significant" catch trends were detected. Key: "LGL" = longline, "POT" = pot, "TWL" = trawl, "slope" = slope of linear fit through the time series of average catches, "dif1" = average 2000-2002 catch minus average 1998-1999 catch, "dif2" = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a "significant" result at the 5% level.

Category		Catch					Measure of Trend		
Area	Gear	1998	1999	2000	2001	2002	slope	dif1	dif2
509	LGL	10,376	12,704	14,413	14,174	16,593	**1,390**	3,520	2,886
543	TWL	121	65	63	43	16	**-23**	-52	-53
610	TWL	14,715	15,074	11,976	6,698	5,435	**-2,693**	-6,858	**-7,855**
620	POT	2,437	3,352	1,912	794	656	-612	-1,774	**-1,842**
630	POT	5,821	6,830	8,637	2,138	1,404	-1,353	-2,266	**-5,325**
630	TWL	18,641	18,159	9,985	13,883	10,608	-2,034	**-6,908**	-3,350
640	LGL	10	11	1	6	5	-2	**-7**	-2
650	LGL	70	33	24	12	8	**-14**	-36	-32
659	LGL	210	142	95	56	20	**-46**	-119	-110

Table 2A.2b. Area-and-month categories in which "significant" catch trends were detected. Key: "slope" = slope of linear fit through the time series of catches, "dif1" = average 2000-2002 catch minus average 1998-1999 catch, "dif2" = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a "significant" result at the 5% level.

Category		Catch					Measure of Trend		
Area	Month	1998	1999	2000	2001	2002	slope	dif1	dif2
509	6	21	12	30	650	1,259	311	630	**933**
509	9	1,418	789	2,130	2,815	3,388	597	**1,674**	1,656
513	3	553	1,597	1,405	2,033	2,855	**504**	1,022	1,259
513	11	441	562	905	799	1,155	**167**	452	341
513	12	488	347	265	121	75	**-105**	-264	-269
517	4	6,349	6,543	4,923	1,652	2,841	-1,191	-3,308	**-3,692**
517	5	312	577	71	62	113	-91	**-362**	-233
521	4	5,593	6,475	2,176	3,139	2,833	-886	**-3,318**	-1,762
521	7	355	498	677	744	1,029	**159**	390	376
541	1	352	352	210	26	8	**-101**	**-270**	**-288**
541	4	2,478	4,163	3,748	239	1,203	-647	-1,590	**-2,741**
543	7	121	65	63	43	16	**-23**	-52	-53
610	2	12,351	9,934	9,789	6,108	6,266	**-1,600**	-3,755	**-4,505**
620	3	6,390	3,795	910	468	672	-1,477	**-4,410**	-3,129
630	1	3,557	4,545	4,453	1,969	1,570	-655	-1,387	**-2,416**
630	3	8,826	10,304	3,619	2,414	6,142	-1,326	**-5,507**	-3,305
630	6	43	54	21	31	25	-6	**-23**	-11
630	9	80	103	28	1,121	1,055	297	643	**1,017**
650	6	12	13	3	5	6	-2	**-8**	-4
659	3	51	36	28	18	2	**-12**	-27	-28
659	4	49	23	16	5	2	**-11**	-28	-26
659	6	10	16	6	3	4	-2	**-9**	-7
659	9	13	7	8	3	1	**-3**	-6	-7
659	10	8	10	8	1	0	-2	-6	**-8**
659	11	14	22	2	3	1	-5	**-16**	-11

Table 2A.2c. Gear-and-month categories in which "significant" catch trends were detected. Key: "LGL" = longline, "POT" = pot, "TWL" = trawl, "slope" = slope of linear fit through the time series of catches, "dif1" = average 2000-2002 catch minus average 1998-1999 catch, "dif2" = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a "significant" result at the 5% level.

Category		Catch					Measure of Trend		
Gear	Month	1998	1999	2000	2001	2002	slope	dif1	dif2
LGL	4	8,459	8,375	1,672	2,882	2,417	-1,758	**-6,093**	-3,519
LGL	6	110	120	54	64	52	-17	**-59**	-37
LGL	9	3,833	7,785	12,663	13,221	12,291	2,235	**6,916**	4,662
POT	1	1,879	2,696	2,425	345	224	-566	-1,289	**-2,049**
TWL	1	4,788	3,554	4,488	1,095	1,625	-878	-1,768	**-2,916**
TWL	2	27,491	27,650	27,588	14,765	18,283	-3,130	-7,358	**-11,052**
TWL	6	21	12	30	650	1,259	311	630	**933**

Table 2A.3a. Area-gear-month categories in which "significant" catch trends were detected. Key: "LGL" = longline, "POT" = pot, "TWL" = trawl, "slope" = slope of linear fit through the time series of catches, "dif1" = average 2000-2002 catch minus average 1998-1999 catch, "dif2" = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a "significant" result at the 5% level.

Category			Catch					Measure of Trend		
Area	Gear	Month	1998	1999	2000	2001	2002	slope	dif1	dif2
509	LGL	9	95	457	1,082	2,142	3,317	**813**	1,905	**2,185**
509	TWL	6	21	12	30	650	1,259	311	630	**933**
513	LGL	11	441	562	905	799	1,155	**167**	452	341
513	LGL	12	488	347	265	121	75	**-105**	-264	-269
517	LGL	4	1,446	1,723	267	167	29	-439	**-1,430**	-1,047
517	LGL	10	3,217	2,766	2,797	1,727	1,897	-368	-851	**-1,114**
517	TWL	1	2,587	1,544	2,886	443	446	-538	-807	**-1,895**
517	TWL	4	4,903	4,821	4,656	1,485	2,811	-752	-1,878	**-2,645**
517	TWL	5	312	577	71	62	113	-91	**-362**	-233
521	LGL	4	5,197	4,712	721	2,607	2,104	-829	**-3,144**	-1,188
521	TWL	7	355	498	677	744	1,029	**159**	390	376
541	LGL	4	1,752	1,895	629	90	266	-478	**-1,495**	-1,247
541	TWL	1	352	352	210	26	8	**-101**	**-270**	**-288**
543	TWL	7	121	65	63	43	16	**-23**	-52	-53
610	LGL	1	1,180	1,159	1,216	1,726	1,416	104	283	**386**
610	TWL	2	10,431	8,000	7,094	4,026	3,539	**-1,776**	-4,329	**-4,726**
620	POT	2	1,412	1,472	1,408	564	284	-317	-690	**-1,007**
620	POT	3	1,025	1,880	505	229	372	-296	**-1,084**	-836
630	LGL	6	43	54	21	31	25	-6	**-23**	-11
630	LGL	10	37	25	20	9	6	**-8**	-19	-20
630	POT	1	1,879	2,696	2,425	345	224	-566	-1,289	**-2,049**
630	TWL	2	5,472	5,171	3,923	3,496	2,963	**-669**	**-1,861**	-1,626
630	TWL	3	6,723	6,726	1,903	1,798	4,188	-1,000	**-4,095**	-2,125
650	LGL	6	12	13	3	5	6	-2	**-8**	-4
659	LGL	3	51	36	28	18	2	**-12**	-27	-28
659	LGL	4	49	23	16	5	2	**-11**	-28	-26
659	LGL	6	10	16	6	3	4	-2	**-9**	-7
659	LGL	9	13	7	8	3	1	**-3**	-6	-7
659	LGL	10	8	10	8	1	0	-2	-6	**-8**
659	LGL	11	14	22	2	3	1	-5	**-16**	-11

Table 2A.3b. Area-gear-month categories in which "significant" trends in the number of processors were detected. Key: "LGL" = longline, "POT" = pot, "TWL" = trawl, "slope" = slope of linear fit through the time series of processor numbers, "dif1" = average 2000-2002 catch minus average 1998-1999 catch, "dif2" = average 2001-2002 catch minus average 1998-2000 catch. Bold font indicates a "significant" result at the 5% level.

Category			Processors					Measure of trend		
Area	Gear	Month	1998	1999	2000	2001	2002	slope	dif1	dif2
509	LGL	9	7	4	13	18	15	3.0	**9.8**	8.5
509	TWL	3	32	27	39	40	36	2.1	**8.8**	5.3
509	TWL	6	4	3	5	8	10	**1.7**	4.2	**5.0**
513	TWL	7	10	11	14	14	15	**1.3**	**3.8**	2.8
513	TWL	9	35	29	31	23	23	-3.0	-6.3	**-8.7**
514	TWL	5	10	8	9	3	5	-1.5	-3.3	**-5.0**
517	LGL	4	12	14	5	5	3	-2.7	**-8.7**	-6.3
517	LGL	10	23	21	21	19	19	**-1.0**	-2.3	-2.7
517	TWL	4	23	22	26	19	18	-1.3	-1.5	**-5.2**
517	TWL	9	35	34	31	31	27	**-1.9**	-4.8	-4.3
519	TWL	7	3	4	6	8	6	1.0	**3.2**	2.7
521	LGL	4	20	19	6	9	7	-3.6	**-12.2**	-7.0
521	LGL	9	22	22	19	25	26	1.1	1.3	**4.5**
521	TWL	7	5	11	16	22	24	**4.9**	**12.7**	12.3
523	LGL	10	8	6	4	4	3	**-1.2**	**-3.3**	-2.5
541	TWL	3	26	21	15	11	14	-3.4	**-10.2**	-8.2
542	TWL	2	7	5	7	9	11	1.2	3.0	**3.7**
610	TWL	3	16	10	10	6	6	**-2.4**	-5.7	-6.0
610	TWL	10	5	4	4	10	9	1.4	3.2	**5.2**
620	TWL	2	11	9	8	7	7	**-1.0**	-2.7	-2.3
620	TWL	10	15	12	4	7	8	-1.9	**-7.2**	-2.8
630	LGL	7	18	21	12	7	7	-3.6	**-10.8**	-10.0
630	LGL	10	16	15	13	9	10	**-1.8**	-4.8	**-5.2**
630	TWL	3	11	13	8	9	7	-1.2	**-4.0**	-2.7
630	TWL	7	19	17	13	13	12	**-1.8**	**-5.3**	-3.8
630	TWL	10	12	12	9	8	7	**-1.4**	**-4.0**	-3.5
659	LGL	5	9	10	10	7	5	-1.1	-2.2	**-3.7**
659	LGL	6	11	10	11	8	8	-0.8	-1.5	**-2.7**

Table 2A.4. Summary of "significant" positive catch trends. The first part of the table lists months with positive trends, the second part lists area-and-gear categories with positive trends, the third part lists area-and-month categories with positive trends, the fourth part lists gear-and-month categories with positive trends, and the fifth part lists area-gear-month categories with positive trends. Each positive trend is reported in terms of tons and as a percentage of the average total catch (186,271 t). In cases where the "slope" measure of trend was "significant", the change in tons is shown as twice the slope, to make this statistic comparable to "dif1" and "dif2" (see Tables 2A.1-2A.3). In cases where more than one measure of trend was "significant," the measure with the largest magnitude is used here.

Month	Change (t)	Change (%)
6	896	0.5
9	6,976	3.7
Total	7,872	4.2

Area	Gear	Change (t)	Change (%)
509	LGL	2,781	1.5
	Total	2,781	1.5

Area	Month	Change (t)	Change (%)
509	6	933	0.5
509	9	1,674	0.9
513	3	1,008	0.5
513	11	333	0.2
521	7	319	0.2
630	9	1,017	0.5
	Total	5,285	2.8

Gear	Month	Change (t)	Change (%)
LGL	9	6,916	3.7
TWL	6	933	0.5
	Total	7,850	4.2

Area	Gear	Month	Change (t)	Change (%)
509	LGL	9	2,185	1.2
509	TWL	6	933	0.5
513	LGL	11	333	0.2
521	TWL	7	319	0.2
610	LGL	1	386	0.2
		Total	4,157	2.2

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